

Sanitary Qualities
of the
Sudbury, Mystic
Shawshine and
Charles River
Waters.

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OF THE

MEDICAL COMMISSION

UPON THE

SANITARY QUALITIES

OF THE

SUDBURY, MYSTIC, SHAWSHINE, AND CHARLES
RIVER WATERS.



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CITY OF BOSTON.



REPORT
OF THE
MEDICAL COMMISSION
UPON THE
SANITARY QUALITIES
OF THE
SUDBURY, MYSTIC, SHAWSHINE, AND CHARLES
RIVER WATERS.

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CITY OF BOSTON.

To His Honor Samuel C. Cobb, Mayor of Boston: —

The Medical Commission appointed in pursuance of the following order —

IN BOARD OF ALDERMEN, June 15, 1874.

Ordered, That His Honor the Mayor be requested and empowered to appoint three physicians, who shall, at an early opportunity, examine and report upon the comparative desirability on sanitary grounds of the Sudbury, Mystic, Shawshine and Charles river waters; and that the expense of such investigation be charged to the appropriation for an additional water supply —

has the honor to submit the following

REPORT.

PART FIRST.

GENERAL CONSIDERATIONS.

In an investigation of the relative merits of different rivers as sources of water supply for domestic purposes, the following subjects of inquiry naturally present themselves: —

I.

Nature of the soil and configuration of the land where the rivers rise and flow.

II.

Color, taste and general appearance of the water.

III.

Sources of pollution : —

- (a) Vegetable substances.
- (b) Sewage (direct and indirect).
- (c) Drainage from cemeteries.
- (d) Manufacturing refuse.

IV.

Density of population in drainage areas, and probable future increase of the same.

V.

Chemical composition of the water.

VI.

Opportunities for storage.

The bearing of these different subjects on the general question may be considered in the order in which they have been mentioned.

I. NATURE OF THE SOIL AND CONFIGURATION OF THE LAND
WHERE THE RIVERS RISE AND FLOW.

The nature of the soil will, of course, affect the character of the water flowing through it, particularly in regard to its inorganic constituents. If the soil is rich in soluble mineral substances, these will be dissolved out, and, if they are compounds of lime and magnesia, will cause an increased hardness of the percolating water. If the soil is impregnated with the products of vegetable decomposition, these will also, as far as they are soluble, be removed by the water in its subterranean course.

Upon the configuration of the land through which a river flows depends the extent to which the adjacent country is flooded in periods of freshet, and upon the extent of this flooding and the character of the vegetation on the surface flooded depends, to a great extent, the amount of vegetable impurities which the river water contains.

In regard, however, to the nature of the soil and the configuration of the land, the four drainage areas under consideration are so far alike, that no difference in the river water, due to these causes, is likely to persist after storage has been effected in the basins provided in all the proposed schemes. This subject may, therefore, be dismissed with the above general remarks, the question of the influence of mineral and vegetable impurities on the salubrity of the water being left for future consideration.

II. COLOR, TASTE AND GENERAL APPEARANCE OF WATER.

Conclusions as to the character of water drawn from its color, taste and general appearance are liable to be very erroneous. It is perfectly possible for water to be polluted in a way to render it entirely unfit for domestic purposes, and yet to sight and taste give no evidence of this pollution.

As an instance of this sort of contamination, may be mentioned the condition of the well-water of the Bay View House, the hotel at Mt. Desert, where typhoid fever prevailed in the summer of 1873. The water was described by the physician who collected it on the spot as "clear and sparkling;" yet, when submitted to analysis some weeks later, it was, in the words of the chemist who examined it, "very turbid, the sediment appearing white when in suspension, but after settling it had a light brown color. Its odor was vile, resembling that of bilge-water, and the presence of sulphuretted hydrogen was easily distinguishable. . . . The amount of sediment was so great as to render a layer of the water one inch in thickness non-transparent, and a

microscopic examination revealed in it the presence of ordinary animalculæ, vibriones and fungi, such as are seen in liquids containing decomposing organic matter. The above examination, although very hastily performed, gives results which prove beyond a doubt that the water is totally unfit for drinking purposes, and that it must be contaminated in some manner by drainage. The sulphuretted hydrogen must have been formed by the decomposition of some organic material which contains sulphur, such as albumen, and its presence is in itself sufficient evidence of the pre-existence of such organic material in the water. The sediment and vile odor were developed by decomposition of the organic matter contained in the water after its introduction into the vessel.¹

It would be easy to multiply cases of this sort, but it will be sufficient to mention an instance furnished by our own investigations. The water of Angle brook, one of the tributaries of Sudbury river, appeared to us, at the time of our visit, remarkably pure and agreeable to the taste; yet the chemical analysis indicates that, in all probability, the sewage of the growing town of Marlboro finds its way into it.

Although our unaided senses do not always enable us to detect pollution from sewage, yet in some other respects the color and general appearance of water is a more trustworthy indication of its composition.

Almost all rivers flowing through a fertile country have, especially in summer and autumn, a more or less earthy taste, and a brownish-yellow color, which, to a great extent, disappear by storage in large lakes, though it is impossible, in the present state of our knowledge of the movements of underground water, to decide how far this is due to a change in the river-water itself, and how far it is dependent on a dilution of the river-water with a purer water filtered through the soil and entering the lake by underground channels.

Whatever may be the precise nature of the substance which

¹ Boston Med. and Surg. Journal, vol. 89, p. 494.

gives its brownish-yellow color to river-water, it is undoubtedly of vegetable origin, and probably a product of vegetable decomposition; but to what degree its presence renders the waters unwholesome is a question yet to be decided. As above stated, the color disappears more or less completely on storage, though the nature of the process producing this change has not been satisfactorily determined.

An account of some experiments, made with a view of determining upon what constituent of river-water its color depends, and also in what way storage affects the color and chemical composition of water, will be found in Appendix B.

III. SOURCES OF POLLUTION OF RIVERS.

Rivers are polluted by refuse materials derived from vegetation, population and manufactures. Such materials may be mineral, vegetable or animal, or combinations of these; they may be received by the water-courses fresh and unchanged, or in process of conversion, or already converted, to inorganic and perhaps innocuous chemical compounds, or they may be in various stages of decomposition and putrefactive decay. The degree of contamination, other things being equal, will depend upon the directness with which the waste materials are poured into the streams, being greatest in direct or pipe-drainage, and least in percolation through the natural soil. Between these two extremes lie various artificial modes and natural channels of conveyance.

The following classification presents in more detail the various sources of pollution:—

1. Vegetable substances.

- (a) Aquatic and terrestrial growths.

- (b) Peaty deposits.

- (c) Parts of manufacturing refuse.

2. Sewage:—

- (a) Human excreta and kitchen slops. These are animal, vegetable and other material.

- (b) Wash-house slops, containing soap, and animal matter from soiled linen.
 - (c) Drainage from slaughter-houses ; animal matters and some vegetable.
 - (d) Drainage from stables, cow-houses and piggeries,— animal and vegetable.
3. Drainage from cemeteries.
4. Manufacturing refuse, — from
- (a) Tanning and currying establishments.
Glue and glue-stock factories.
Paper-mills.
Wool-scouring establishments.
Woollen, shoddy and felting-mills.
 - (b) Cotton, batting, thread and twine factories.
 - (c) Dye, print, bleach and paint works.
Chemical works and soap-factories.
Gas works.
 - (d) Saw, grist and emery mills, cabinet, tool and machine-shops, and various other works not elsewhere mentioned.

Inasmuch as the special treatment of each one of these sources of contamination does not come within the scope of the present inquiry, and as it may be assumed that the specific differences of works of the same name in eastern Massachusetts will not materially affect the main question, it will be sufficient to state broadly that, of all the kinds of refuse enumerated or implied in the above list, sewage, as containing human excreta, is the one most to be feared. Similar in kind, but less in degree, are the washings of house-linen and the filthy rags supplied to paper-mills. Next in order, but of a different kind, are waste liquors containing animal mat-

ters, especially animal matters in a state of decomposition. Pre-eminent among these are the tanneries, whose waste liquors are said to possess from five to ten times the manurial power of average sewage, and following upon these at greater or less distances are the glue factories, wool-scouring establishments, the shoddy and woollen mills and soap works. Others are principally dirty or offensive; while dye and chemical stuffs form the principal pollution of a large class of works and enter secondarily into the waste products of many other industries. Cemeteries may be classed with decomposing animal matters, leaving for future study to determine the question whether the drainage of these places is a bearer of specific poisons.

It is plainly desirable, on sanitary grounds, to avoid the admission to drinking water of any kind of filth or refuse matter. Let authorities differ as to what constitutes pollution, and as to the degree and kind of danger to be apprehended from a particular sort, they are in the main agreed that the contaminations which ordinarily occur may impair health and predispose to disease, even if they do not produce a direct and specific effect. It is not safe to say that "filth is only matter in a wrong place," without recognizing the occasionally fatal consequences of such malposition.

Dr. F. Fischer, in his pamphlet on "Drinking-water," etc., Hannover, 1873, says:—

"Although no perfect unanimity of opinion is as yet reached,—inasmuch as some ascribe to water only a *predisposing* influence,—it is agreed that the spread of cholera and other diseases is somehow connected with drinking-waters. Already, wherever radical reforms in the matter of water-supply and sewerage have been introduced, have appeared, *pari passu*, improvement in the general health, lessening of mortality, and marked abatement of infectious epidemic diseases and epidemics.

"Moreover, the possibility of drinking bad water without

getting typhus or cholera needs not to be argued. Bad air, spoiled water (where these, perhaps, have not taken up the infectious material itself) have only a predisposing effect. They weaken the power of resistance to infection."

The late Secretary of the State Board of Health (Report of 1871, p. 178) says:—

The single continuous thread of probability which we have been able to follow in this inquiry leads uniformly to the *decomposition of organized* (and chiefly vegetable) *substances* as the cause of typhoid fever as it occurs in Massachusetts.

"Whether the vehicle be drinking-water made foul by human excrement, sink-drains, or soiled clothing; or air made foul in enclosed places by drains, decaying vegetables, or fish (Swampscott); or old timber (Tisbury); or in open places by pigsties, drained ponds, or reservoirs, stagnant water, accumulations of filth of every sort,—the one thing present in all these circumstances is decomposition."

There is a very general opinion, especially strong in England, that the drinking of water containing sewage, which has become impregnated with the discharges of persons suffering from cholera or typhoid fever, is capable of reproducing either of those diseases respectively; and even that specific contamination of the sewage is not a necessary condition to the production of typhoid fever, dysentery, diarrhœa, scarlatina, and some other diseases.

Surgeon Major A. C. C. De Renzy, Sanitary Commissioner, Punjab, writing on the extinction of typhoid fever in the Millbank prison, by the disuse of Thames water, feels warranted in saying ("Lancet," 1872, Vol. I., p. 821):—

"That, since some of the ablest physicians in London failed for many years to detect the true cause of the unhealthiness of Millbank prison, and assigned causes for it which later experience has found to be unconnected with it, the probability is that a similar error is frequently made

elsewhere, and that the prevalence of some zymotic diseases is ascribed to locality, malaria, heat, cold, variations of temperature, moral depression, and other intangible influences which could be entirely removed by the general disuse of impure water."

"That, as it required long years of observation to establish the noxious influence of Thames water in Millbank, even when well filtered, under conditions very favorable for detection, we should be cautious in accepting the opinion, based on the results of chemical analysis, that the use of that water by the population of London is free from danger."

Wm. Budd, M.D., F.R.S., in his work entitled "Typhoid Fever, its Nature, Mode of Spreading, and Prevention," 1873, says:—

"Now I have no difficulty in at once giving my opinion that *all* the emanations from the sick are, in a certain degree, infectious. At the same time, it is one of the principal objects of the work to show that what is cast off from the intestines is incomparably more virulent than anything else."

Mr. J. Simon, F.R.S., Medical Officer to the Privy Council, and Surgeon to St. Thomas' Hospital, in giving evidence before the Royal Commission on Water Supply of London, said:—

"I think that where the population of any town shows a considerable amount of diarrhœa, and also of typhoid fever, it makes one believe that there must be some impurity in the water at times, and the health of the people as regards those diseases of the intestine seems to be very much influenced by the purity or impurity of its water-supply (p. 73)."

"Q. But you have not been able in all those cases of suspicion [cholera in London] to trace the cause of the evil which has arisen from the use of those waters?"

"A. There are certain organic matters in water, peaty matters, for instance, as to which I do not know, of my own

knowledge, that they do any harm. I think it would be safer, that it should be without any organic admixture. But with regard to some of those matters we do know that they do harm. The water which has done very great harm in London on various occasions, as we believe, has been water conveying what, by a figure of speech, I may call the actual seeds of specific disease. Chemists cannot identify those seeds. What one has to do is to guard the supply with utmost strictness against every foul admixture. It should be made an absolute condition for a public water-supply, that it should be uncontaminable by drainage."

Dr. R. A. Smith, in the same report, says, "It is not the mere amount of organic nitrogen that is of the greatest consequence, but the condition of that matter, whether it is in a state ready to putrefy or give out germs of life, vital forms. If there is neither putrefaction nor vitality, I do not see how it can affect us."

The water-supply should be "uncontaminable by drainage." There is no demonstrable safety in a middle course. No one has conclusively shown that it is safe to trust to dilution, storage, agitation, filtration or periods of time for the complete removal of disease-producing elements, whatever these may be. Chemistry and microscopy cannot and do not claim to prove the absence of these elements in any specimen of drinking-water. They discover pollution; and pollution is somehow intimately associated with the production of certain diseases. Our germ, fermentation and other theories indicate our actual ignorance of the ultimate nature of that cause or those causes whose action we nevertheless rightly infer. These deductions from the observations of cases and their surroundings have been so often repeated that we cannot afford to disregard them. The proof is especially strong of the influence of sewage contamination of city wells upon the health of those using the waters. Chemistry in these cases has been invaluable in pointing out the fact and

source of contamination; but it has not indicated the quantity and quality of the specific cause. This may not be susceptible of dilution or oxidation. In order, therefore, to feel sure that our drinking-water is healthy, it is correct, so far as our sanitary knowledge extends, to exclude wholly every species of contamination, however difficult, practically, this may be declared to be.

In this connection we present the testimony of the Rivers' Pollution Commission, First Report, Vol. I., 1870, p. 113:—

"The importance of the history of water as regards its anterior pollution with organic matters of animal origin does not arise from the presence of the inorganic residues (nitrates, nitrites and ammonia) of the original polluting matters, for they are in themselves innocuous; but from the risk lest some portion of the noxious constituents of the original animal matters should have escaped that decomposition which has resolved the remainder into innocuous mineral compounds. And the danger is the more to be feared because it is quite impossible by chemical analysis, or indeed by any other process of investigation short of administration of the water to human beings, to discover whether or not such noxious substances are still left in the water. We cannot but regard this risk as considerable, whatever may be the nature of the noxious ingredient in excrementitious matters, but if we are to accept the theory which is now prevalent amongst many physiologists who have closely studied the subject of the spread of epidemic and infectious diseases, that these diseases are propagated by minute zymotic germs, the danger becomes much augmented on account of the great resistance which such organic and living germs oppose to the oxidizing agencies which gradually decompose and destroy dead organic matter. That this is no imaginary danger is evident from the numerous outbreaks of typhoid fever and cholera which have been distinctly traced to the drinking of water previously polluted by

excrementitious matters, but in which chemical analysis failed to detect any noxious ingredient." . . .

In his evidence before the Royal Commission on Water Supply, Mr. Simon, F. R. S., thus expresses his opinion on this subject: — . . .

"Q. Supposing that sewage is discharged from one of the sewers, say at Windsor, would it be possible to detect the presence of that sewage seven miles lower down the river, having regard to the volume of water in the river?

"A. I believe it would be absolutely impossible for chemists to discover it; but the practical sanitary question is different. Supposing tape-worm eggs to be sent into the river with that sewage, would those tape-worm eggs be alive seven miles down? Or supposing cholera discharges to be sent into the river, or the discharges of typhoid fever, and assuming (which is a frequent pathological opinion) that the respective contagia of typhoid fever and cholera are living germs, would those germs be alive seven miles down? It is not a question whether a chemist would find out the organic matter so much as it is a question whether those particular molecules would still have their property seven miles down. I cannot say that they would not.

"Q. Could you detect them at that distance?

"A. Only by their effects.

"Q. Might not the same disease be produced from any other cause?

"A. The particular parasite will only come from its particular egg. You could not get hydatids except from eggs any more than you could get chickens without eggs.

"Q. If it is not possible for a chemist to discover sewage, is it not presumptive evidence either that it does not exist, or that, if it does exist, it is in such minute quantities that it is in no way deleterious to human health?

"A. I am very decidedly of opinion that that principle is not

a safe one to adopt as a basis for sanitary regulations in the matter. . . . I think the drinking of such water is dangerous. It is not practicable to define the exact line at which the danger in a particular case begins. Everybody knows that water with certain obvious pollutions by sewage is fatal to health, and I do not know where to draw the line in practice between such cases and those which are, practically speaking, unimportant."

Sir Benjamin Brodie, Bart. (Rivers' Pollution Commission, First Report, River Thames, Vol. II., Minutes of Evidence, page 49), says, in effect:—

"I should say that it is simply impossible that the oxidizing power acting on sewage running in mixture with water over a distance of any length is sufficient to remove its noxious quality. . . . I presume that the sewage could only come in contact with the oxygen from the oxygen contained in the water, and also from the oxygen on the surface of the water; and we are aware that ordinary oxygen does not exercise any rapidly oxidizing power on organic matter. I believe that an infinitesimally small quantity of decayed matter is able to produce an injurious effect upon health. Therefore, if a large proportion of organic matter was removed by the process of oxidation, the quantity left might be quite sufficient to be injurious to health. With regard to the oxidation, we know that to destroy organic matter the most powerful oxidizing agents are required; we must boil it with nitric acid and chloric acid, and the most perfect chemical agents. To think to get rid of organic matter by exposure to the air for a short time is absurd."

The Commission before whom the above testimony was given summarize the results of their thorough investigation into the alleged self-purification of polluted rivers as follows:—

"Thus, whether we examine the organic pollution of a river at different points of its flow, or the rate of disappear-

ance of the organic matter of sewage when the latter is mixed with water and violently agitated in contact with air, or, finally, the rate at which dissolved oxygen disappears in water polluted with five per cent. of sewage, we are led in each case to the inevitable conclusion that the oxidation of organic matter in sewage proceeds with extreme slowness, even when the sewage is mixed with a large volume of unpolluted water, and that it is impossible to say how far such water must flow before the sewage matter become thoroughly oxidized. It will be safe to infer, however, from the above results [referring to actual experiments previously detailed], that there is no river in the United Kingdom long enough to effect the destruction of sewage by oxidation."

While the medical journals of the past few years abound with examples of disease ascribed to admixture of sewage with drinking-water, the cases are rare which can be distinctly traced to some form of manufacturing refuse. This does not necessarily imply a radical difference between the two classes of pollution, as might at first sight appear, although such difference may exist; but it is the result, rather, of the fact that sewage, while often constituting the sole contamination of water, rarely fails to accompany all other forms of pollution, and thus to complicate the results of observation upon them. The waste from factories being usually more or less associated with sewage, whether in subsoil waters or in streams, cannot easily be distinctively accused of causing an outbreak of disease which happens in the immediate neighborhood. But we can anywhere find a community whose supply of drinking-water may demonstrably contain sewage and at the same time be wholly free from suspicion or possibility of other contamination. We may best study that part of manufacturing refuse whose chief objectionable quality is the presence of putrescible organic, i. e., animal, matter, which is also the chief character of most sewage, by observing, not

the factories and their streams, but the pure well water occasionally the recipient of some dead animal.

Alfred Carpenter, M. D., Lond., has apparently traced some outbreaks of scarlatina to air contaminated by decaying slaughter-house refuse spread upon the ground, and in this connection has raised the question of danger from the presence of blood in sewers. Slaughter-house refuse and scarlatina have been associated by other observers as having possibly the relation of cause and effect. Dr. Edward Smith, in his book on "Foods" (1874, p. 308), says: "An instance was recorded by us, many years ago, in which a very violent type of scarlet fever was associated with drinking water from a tank in which herrings in a state of decomposition were found."

Examples of this sort might be multiplied and testimony accumulated in support of the general proposition that manufacturing refuse renders water unfit to drink. But we practically condemn the admission of all filth without waiting for scientific reasons or demonstrative proof. That which is in any way offensive to the sight, taste or smell, or the sense of decency or propriety, has no more right to a part in the composition of our drinking-waters than those substances which are actually proved to be deleterious to health. The effect of some forms of manufacturing refuse upon the lower animals is worthy of notice. It is well established that tanneries, paper-mills and gas-works kill and drive off fish, and it is a fair inference that various other works discharging mineral or putrefactive substances have a like effect (see first report of Commissioners, etc.—River Thames, 1866, Vol. II.), notwithstanding certain species of animals seek out and thrive upon some forms of filth. The effect upon vegetable life, on the other hand, is no evidence of the purity or impurity of a water-supply. Sewage in some situations may cause a rank growth, while in others it kills. The long grass in the bed of the Charles, at Careyville, has apparently thriven upon it

occasional bath of dyestuffs from the shoddy-mill just above. If we recognize the principle upon which aquaria are managed, we shall not be surprised at such results, nor be in danger of drawing a false inference from rank vegetable life of the effect of a particular form of pollution upon the health of mankind. In those cases where vegetation suffers or disappears, or where all forms of vitality seem overborne, we may reasonably infer serious contamination.

Judging by a series of experiments performed by Dr. F. Crace Calvert and reported by him at a meeting of the Association of Medical Officers of Health, London ("Lancet," 1872, Vol. I., p. 129) there is little hope of the accidental destruction, by the discharges from chemical works, of low forms of organic life, such as may be associated with putrefactive changes. "Chloride of lime, or bleaching powder, instead of stopping, actually promoted the decomposition of the albumen liquid — vibrios were found in great abundance, but no fungi. . . . Acids promoted the formation of fungi, particularly the sulphuric and acetic. Alkalies promoted the formation of vibrios, and prevented the growth of fungi. Soda produced little or no effect. Ammonia and lime promoted the putrescence and had very little effect on the microscopic life."

A comparison of the natural advantages of the four drainage areas for the proper disposal of sewage and manufacturing refuse, being largely concerned with the question of relative expense, belongs to the present report only in its sanitary aspects. It may be safely said, that the most complete, and, therefore, the safest removal of the various forms of pollution is attainable only by a system of town sewerage terminating outside the valley whose waters we wish to protect; that next in order of thoroughness is a system of sewerage terminating in such way as to give opportunity for irrigation combined with filtration, and preferably intermittent filtration, through the largest possible extent of natural soil; and,

finally, that it is not safe to trust to the filtering and purifying power of the soil in the neighborhood of streams even where soakage altogether takes the place of surface or other drainage.

Sir Benj. Brodie, Bart., Professor of Chemistry at Oxford, gave the following testimony before the Royal Commission on Water Supply of London:—

“Q. What course do you consider the most efficacious one to get rid of the sewage contamination from the towns on the river?

“A. The best is, not to put the sewage with the river at all. That is the best answer I can give, and indeed that is the only course by which you can be certain you have not got it in. I certainly do think it a very good thing to employ the processes used for the filtration and destruction of sewage, and they are, *pro tanto*, beneficial. They really help the matter a good deal, but I do not think they are entirely effectual. There is no known process that I am aware of for, on a large scale, destroying the injurious quality of sewage.”

The “Lancet” (Lond.), in an editorial (1872, Vol. II., p. 46), says:—

“Loose porous soil—such as gravel or broken chalk—is not only more liable to drainage contamination, but affords a more imperfect filter than closer soil. Very shallow porous soils are often exceedingly foul from the stagnation and accumulation in them of manurial matters. The dip of the land is also an important element in the study. A cesspool below a well on a hill-side may not pollute the water; but if above, the water will be almost sure to suffer. A short time ago we analyzed the water of two wells, one at the bottom, and one near the top, of the same hill. The former showed almost exactly three times the amount of contamination of the latter.”

The same journal, speaking of natural filtration (editorial, 1872, Vol. I., p. 370), says:—

"There is all the difference in the world between filtration through a bed of chalk 500 feet thick, and filtration through 20 feet of loose gravel, saturated already with the foul soakage of middens, farm-yards, and factories. These are the extremes. Between them lies an infinite series of possible cases."

In "The Report upon the Sanitary Condition of the Districts of the Combined Sanitary Authorities of Oxfordshire, by Gilbert W. Child, Officer of Health to the above Authorities," quoted in the "Lancet," 1874, Vol. I., p. 841, it is stated that, at Charlbury, in consequence of the escape of the contents of a barrel of petroleum or benzoline, which had been buried in an orchard, a circuit of wells, 60 feet below and 250 or 300 yards distant, became so affected that the occupiers of 15 houses, containing 82 inhabitants, were, for 10 days, unable to use the water for drinking or cooking. The cattle of one of the proprietors, moreover, refused to drink at the spring where they were accustomed to drink." "The hole, in which the cask was buried, must have been immediately over the head of the spring which supplied the wells." "Had this soakage been sewage instead of petroleum, who can doubt that the result might have been wholesale water-poisoning, and an outbreak of typhoid fever?"

The polluted well at Mt. Desert, referred to elsewhere in this report, must have derived its contamination from a cesspool up the hill, and on the opposite side of the hotel. The sewage must have taken a subsoil course, either about the house or beneath its cellar.

"The careful investigations which have been made in Berlin indicate that the subsoil waters are constantly moving towards the river." (Dr. Fischer, op. cit.)

The view which now prevails with regard to subsoil waters is, that, having no remote and mysterious origin in the bowels of the earth, they are neither independent of surface conditions nor inexhaustible; but are simply derived from

the rainfall and dew of the natural basin, or drainage area, in which they occur. It follows that springs are but the outcropping and overflowing lip of a natural basin, and that the rivers represent the hydrostatic level of the subsoil waters of a drainage area. There is, then, one round of changes; evaporation, condensation, and flow, upon or beneath the surface of the soil, towards and with the visible streams.

We have quoted various isolated examples and statements with which this general view of subsoil waters is entirely in accord. It would seem, therefore, that the undrained towns, factories, and houses of a drainage area may pollute the streams even when not situated directly upon them.

The foregoing considerations, in which an attempt has been made to give expression to the most definite views which we have been able to collect from trustworthy authorities, embrace the following principal points:—

First. The danger to health from the pollution of drinking-water.

Second. The impossibility of demonstrating the absence of danger by an examination of the water.

Third. The difficulty of purifying a stream once polluted.

Fourth. The polluting effect of undrained towns by the agency of subsoil waters.

These points indicate the necessity of treating the various forms of pollution by strictly preventive measures, the relative cost of which in the several drainage areas is a question for engineers to decide; also, the absolute value of estimates of population and manufactures, as sources of pollution, and, to some extent, the relative value of such estimates for the varying condition of towns as to drainage and proximity to water-courses.

IV. DENSITY OF POPULATION IN DRAINAGE AREAS AND PROBABLE FUTURE INCREASE OF THE SAME.

The density of population in a given drainage area may, in a general way, be regarded as a measure of the extent to which the rivers are likely to be polluted by sewage and refuse. The mode of distribution of the population will, however, affect any conclusions drawn from data of this sort. A population collected chiefly in cities or large towns provided with sewers opening directly into the rivers will, of course, pollute the water far more than the same population scattered more uniformly over the country. But when a comparison is to be made between several drainage areas in which the *distribution* of the population is essentially the same, then its *density* will furnish a tolerably accurate criterion of the danger likely to arise from contamination of the water by sewage and refuse.

Moreover, when a river has been selected as a source of water-supply for a city, it is of the highest importance that all direct sewage and manufacturing refuse of a deleterious nature should be excluded from its waters. A knowledge of the density of the population in the river valley will then be valuable as indicating the probable amount of pollution from indirect sewage and other sources of contamination against which no legislation can guard.

It will be seen that the four rivers under consideration differ greatly from each other in this respect.

Were it possible to determine the future rate of increase of population in any given drainage area, we should be able to pronounce with much greater positiveness upon the advisability of using its rivers as a source of water-supply.

This, however, can only be done in a very general way by a consideration of the rate of growth of population in past years and of the industries practised in the drainage area in question. In this respect, too, it will be found that there is

a great difference in the probable future of the four drainage areas under consideration.

V. CHEMICAL COMPOSITION OF THE WATER.

The object of a chemical analysis is to determine, as far as possible, the presence of an injurious amount of those substances in water, which are believed or are known to be deleterious to health. In the present state of chemical science, however, it is impossible to isolate them and determine their nature with certainty, as can be done in the case of the poisonous metals, — arsenic and antimony, for instance. They are chiefly in the form of complex organic substances, so that the chemist is obliged to resort to various processes by which they can be decomposed, and to measure or weigh the products of such decomposition, in order that he may be able to form only an approximate idea of the amounts of these substances present. Or, he can determine the amount of some innocuous compound, which is almost always associated in water with substances which are injurious.

In the report of the "Royal Commission on Water Supply of London" (p. xciii.), we find the following statement: —

"Where a minute quantity of organic matter escapes destruction (by the processes of oxidation, etc.), it would seem that chemistry is not yet sufficiently advanced to pronounce authoritatively as to its exact quality and value." And in the minutes of evidence before the same commission, Mr. Simon, F. R. S., medical officer to the privy council, says, "I mean that the question of good supply or bad supply is not to be judged only by what the chemists, from their laboratories, can tell you of the water. The greater part of the water-supply of London, as you are aware, is pumped from the Thames. That portion is taken from the Thames after one million population has drained into the river. Nothing which chemists, in the present state of their science, can report negatively as to their findings in the London water will

alter the fact of that filthy admixture, and I know that that fact represents a certain amount of danger to the population that receives the water."

The same high authority, in answer to the question, "If it is not possible for a chemist to discover it (sewage contamination), is it not presumptive evidence that it does not exist, or that, if it does exist, it is in such minute quantities that it is in no way deleterious to human health?" says, "I am very decidedly of opinion that that principle is not a safe one to adopt as a basis of sanitary regulations in the matter. I think that the rule ought to be, that no sewage should go into any water that can be used for drinking purposes. Water into which sewage has been discharged is, in relation to the matter now under consideration, an experiment on the health of the population, and I do not think that that experiment ought to be tried."

Sir Benjamin Brodie also considers it impossible for chemists to tell just where the sewage disappears in water, or whether it ever disappears or not.

Such being the case, it is very evident that small amounts of such impurities as may be capable of propagating the most virulent diseases *may* readily escape detection by chemical tests.

The principal injurious substances found in water belong, as before mentioned, to the class of organic compounds, which are made up of different proportions of two or more of the elements, carbon, nitrogen, hydrogen and oxygen. The various methods for estimating the amounts of the organic impurities in water are based upon the determination of the nitrogen and carbon, or of the nitrogen only. Of these different processes, that proposed by Wanklyn and Chapman has been adopted as the best one yet perfected for the estimation of the nitrogenous substances.

This method consists: First, in boiling the water with a little carbonate of sodium, in order to separate the free am-

monia, which gets into the water chiefly by the decomposition of the organic matter, although a very small amount is absorbed from the air and is found in rain-water ; and, second, by converting the remaining nitrogen, which is in combination with other elements in the organic matter, into ammonia by boiling it with a strongly alkaline solution of potassic permanganate. This latter is called the "albuminoid ammonia," to distinguish it from the free ammonia first expelled, since all of the nitrogen in albumen can be thus converted into ammonia.

Another method for estimating the amount of organic matter is by evaporating a certain amount of the water to dryness and igniting the residue, so as to burn off the organic compounds. The difference between the weight of the residue before and after ignition is the weight of the organic substances. Other volatile substances, however, are expelled besides the organic, so that this weight is termed the "organic and volatile," and is always greater than that of the organic compounds properly so called. This method alone, therefore, is not sufficiently accurate for the determination of the organic substances.

In drawing conclusions from the amounts of organic matter present in water, careful distinction must be made between the organic matter of vegetable and that of animal origin, the latter being much the more deleterious. It is a well-received fact, that decomposing animal matter in drinking-water is a fertile producer of intestinal and other diseases. Thus Dr. Wolf¹ gives a large number of cases, which prove conclusively, that bad water produces diarrhoea, and can propagate dysentery, typhoid fever, and cholera, and that such water is frequently clear, fresh and very agreeable to the taste.

Vegetable matter, on the other hand, forms a large part of our ordinary food and drink, and, except when in a state of

¹ *Der Untergrund und das Trinkwasser der Städte.* Erfurt, 1873.

putrefaction, does no injury unless taken in large amounts. Dr. Frankland, in reply to a question asked by the London Water Commission, says, "As far as we know, the presence of organic nitrogen in the form of vegetable organic matter, such as peaty matter, is innocuous unless contained in considerable quantity in water; but when contained in the water in the form of sewage matter, it is believed to be noxious."

Dr. Lyon Playfair, in evidence given before the same commission, says, "The effect of organic matter in the water depends very much upon the character of that organic matter. If it be a mere vegetable matter, such as comes from a peaty district, even if the water originally is of a pale sherry color, on being exposed to the air in reservoirs, or in canals leading from one reservoir to another, the vegetable matter gets acted upon by the air and becomes insoluble, and is chiefly deposited, and what remains has no influence on health. But where the organic matter comes from drainage, it is a most formidable ingredient in water, and is the one of all others that ought to be looked upon with apprehension when it is from the refuse of animal matter, the drainage of large towns, the drainage of any animals, and especially of human beings."

Dr. Ferd. Fischer¹ says, "Organic matters are in themselves harmless; our artificial drinks, and many articles of food, contain them. Yet how dangerous even very small quantities may prove under certain circumstances is shown in dissecting wounds, malignant pustule, etc.

"That a person can drink bad water and not immediately be affected with typhoid fever and cholera is very evident. Bad air and polluted water (if it does not contain contagious matter itself) act as predisposing causes; they render the system less capable of withstanding infection.

¹ *Das Trinkwasser*, Hannover, 1873.

"If a pure drinking-water is necessary in ordinary times, in times of epidemics it is all the more important."

Animal matter or sewage always contains a large amount of chlorine in the form of common salt, which is an abundant constituent of the animal fluids and tissues. Hence the determination of chlorine in water is very important, as showing probable contamination with sewage. If a water contains a large quantity of sewage, it will contain a proportionally large amount of chlorine. Animal or sewage contamination does not, however, afford the only means by which chlorine can find its way into running streams; it can also be derived from manufacturing establishments where a large amount of salt is thrown away with the refuse. The presence of a considerable amount of chlorine in water, therefore, does not necessarily prove animal contamination.

Natural waters, which are not contaminated with sewage, contain a minute amount of chlorine, those located near the sea-coast containing a larger proportion than inland waters.

The following tables give the amount of chlorine in many of the best drinking-waters of Europe, and in certain suspicious waters. (Extracted from Edward Smith's work on "Foods," p. 300.)

In Good Drinking-Waters.

LOCALITY.	CHLORINE. (Parts per 100,000.)	LOCALITY.	CHLORINE. (Parts per 100,000.)
Bassenthwaite Lake	1.29	Rhine	0.20
Buttermere	0.89	Rivington Pike	0.53
Cocker	1.09	Rydal Lake	0.69
Crawley Burn	1.04	Severn above Newtown .	1.35
Crummock Water	0.89	Skiddaw	1.09
Derwent Water	1.29	Swanston Water	1.39
Derwent	1.09	Windermere	0.99
Ennerdale Lake	0.99	Lake Zug	0.27
Grassmere Lake	0.79	Lake Zurich	0.17
Kent	0.90		

In Certain Suspicious Waters.

LOCALITY.	CHLORINE. (Parts per 100,000.)
Liverpool — Bevington Bush well	12.61
" — Soho well	7.51
" — Water Street well	7.94
Congleton — Town pump	3.18
Rochdale — Spring near churchyard	2.98
Kidderminster — Shallow well	8.38
" — Another well	8.20
Leamington — Private well	14.20
Durham — Private well	9.75
Darlington — Blackwell pump	8.45
Kendall — Shallow well	17.00
Witney — Private well	22.90

Besides the chlorine, free ammonia invariably accompanies decomposing animal matter in sewage. Urea, the principal organic constituent of urine, is very rapidly transformed into ammonia and carbonic acid. Hence the presence of a large amount of both free ammonia and chlorine in water generally indicates sewage contamination, and that such water is unfit for domestic purposes. "Albuminoid ammonia" can be obtained from vegetable as well as animal matter, and when a water contains a considerable quantity of it without at the same time containing an excess of free ammonia and chlorine, it is presumptive evidence that vegetable organic matter only is present.

The following tables give the amounts of free and "albuminoid" ammonia in various good town waters, and in certain suspicious waters. (Extracted from Wanklyn and Chapman's "Water Analysis.")

Free and "Albuminoid" Ammonia in Good Town Water.

LOCALITY.	Parts per 100,000.	
	Free Ammonia.	"Albuminoid" Ammonia.
Manchester town water	0.001	0.006
Edinburgh town water	0.000	0.007
Glasgow (Loch Katrine) town water	0.000	0.008
Chester (Dee) town water	0.000	0.007
Scarborough (Yorkshire) town water	0.001	0.006
Oxton (Birkenhead) town water	0.000	0.002
Chelmsford (Essex) town water	0.008	0.002
Leek (Staffordshire) town water	0.000	0.002
Filde Water-works, Lytham, in Lancashire	0.000	0.010
New Supply to Guildford, Surrey	0.000	0.001

Free and "Albuminoid" Ammonia in Various Suspicious Waters.

LOCALITY.	Parts per 100,000.	
	Free Ammonia.	"Albuminoid" Ammonia.
Well at Leek Workhouse	0.002	0.034
Great St. Helen's Pump, London	0.375	0.018
Pump in Bishopsgate Street, London	0.750	0.025
Pump in Draper's Hall, London	0.600	0.031
Pump in Edinburgh	0.021	0.029
Well in Windsor	0.120	0.008
Well in Eton	0.000	0.084
Effluent from Sewage	1.620	0.090

Hardness.—Some of the inorganic compounds, especially the lime and magnesium salts, have been said to have con-

siderable influence upon the health of the people drinking water which contains them. These are the substances which impart to water the property termed hardness.

There is a great difference of opinion among scientific men as to the deleterious or non-deleterious action of hard waters upon the system. Letheby and Wilson consider that hard waters are clearer, cooler, richer in atmospheric air, and less likely to hold organic substances in solution or to contain living organisms, than soft waters. They say also, that hard waters help to furnish the lime and magnesium salts necessary for the support of some of the animal tissues; a much larger amount, however, of these is obtained from our ordinary articles of diet, so that their presence in drinking-water is not necessary for this purpose.

In a report of Dr. Letheby's, we find, that in some of the English towns the mortality appears to be in inverse proportion to the hardness of the waters used. Thus, in London and twenty-four other English towns the hardness is 16° , while the death-rate is 21.9 per 1,000; in Edinburgh, Leith and several other places the hardness is 8° , and the death-rate is 24.9 per 1,000; in Dundee, Glasgow and others where the hardness is only from $1^{\circ}.3$ to $3^{\circ}.8$, the death-rate is 26.1 per 1,000.

It would seem, from these statistics, that the hardness has a very beneficial effect upon the health of the community, but on the other hand Berlin is supplied with water of from 14° to 61° of hardness, and has an average death-rate of 38.9 per 1,000; Magdeburg has a death-rate of 33 per 1,000, with water varying from 27° to 70° of hardness. The deduction of Dr. Letheby's does not seem, therefore, to be universal, and there are so many other conditions that affect the mortality of large cities and towns, that no arguments can be drawn from such statistics in favor of or against a hard water.

On the other hand, Dr. Lersch¹ enumerates a large number of diseases, especially goitre, which are considered to be due to the use of hard water. One of the inorganic constituents which tends to render water hard, viz., sulphate of calcium, or gypsum, has been quite conclusively proved to have an injurious effect upon the health.

M. Bergeret² attributes the production of goitre to the presence of a large amount of sulphates in the system, which condition can be caused by drinking water containing gypsum. In one case cited to prove this, nearly all of the inhabitants of a town which was supplied with drinking-water largely impregnated with this compound were affected with goitre until the water-supply was changed, when the disease ceased to be produced.

In connection with the waters now under consideration, the question of hardness has but slight importance, since they are very decidedly soft waters, all being under 3° of hardness.

It may be said, further, in favor of soft waters for domestic use, that the Vienna commission reported in favor of them, and Dr. Frankland considers water to be the more conducive to health, the fewer salts it contains. The advantage of soft water over hard, for detergent purposes, is unquestioned.

By the following table it will be seen that many of the best drinking-waters now in use in Europe are under 5° of hardness. (From Edw. Smith's work on "Foods.")

¹*Hydrochemie*, Bonn, 1870.

²*Journ. de Pharm. et de Chim.*, Jan., 1874.

Hardness of Various Good Drinking Waters.

LOCALITY.	HARDNESS.	LOCALITY.	HARDNESS.
Bassenthwaite Lake	2.83	Rhine	10.76
Buttermere	1.01	Rivington Pike	3.72
Cocker	2.15	Rydal Lake	3.10
Crawley Burn	6.08	Severn above Newtown . .	3.09
Crummock Water	1.30	Skiddaw	3.37
Derwent Water	1.74	Swanston Water	6.22
Derwent	3.37	Windermere	4.04
Ennerdale Lake	1.45	Lake Zug	9.03
Grassmere Lake	2.70	Lake Zurich	10.61
Kent	3.90		

The Effect of thickly settled Districts upon the chemical Composition of Water. — The effect of thickly settled districts upon well-water is well understood. Where a district is drained by cesspools, all of the kitchen refuse containing vegetable and animal matter in a state of decomposition, as well as the contents of privies and water-closets, is thrown into the cesspools, whence the liquid portions highly charged with organic matter find their way into the surrounding earth to the water level, which is the level of the surface wells. After a longer or shorter time, depending upon the character of the soil, the earth becomes saturated, and will no longer exert a purifying influence. If the well is upon level ground, there is a constant current of water in the subsoil toward the well from the surrounding earth on all sides, and the contaminated water from the cesspool will get into the well on whichever side it is situated; if the well is upon a side-hill the current of water in the subsoil is toward the natural drain of the country, or toward the valley, so that only contaminated water from cesspools situated above the well finds its way

into it, unless the surface of the well is at a lower level than the cesspool. In the water of wells which have been contaminated in this way, we find a large increase in the solid constituents, both organic and inorganic, a large increase of free ammonia and chlorine showing sewage contamination, an increase of "albuminoid" ammonia from both vegetable and animal matter, and sometimes sulphuretted hydrogen, which is produced by the decomposition of the albumen, as in the case of the Mt. Desert well referred to above.

The same principle holds good in the case of running waters, on the banks of which are situated large towns. The brook or river must be the natural drain of the country, and toward this the subsoil water steadily flows, carrying with it in solution the various soluble constituents of the earth through which it has come, and sewage matter also, if the earth has been saturated with it from cesspools in the vicinity. In the case of a running stream thus contaminated, the products of the decomposition of organic matter are not retained to the extent that they are in wells, the volatile products, such as ammonia and sulphuretted hydrogen, readily escaping into the atmosphere, and the non-volatile ones flowing down the stream, and being diluted with the large volume of pure water coming from above. It is, therefore, much more difficult to detect the contamination in a running water than in a well; in fact, where the stream is a large one, it is impossible, the extent of dilution is so great. In the cases of the small streams we have been enabled to study this effect quite satisfactorily, since the waters were collected during a dry season, and there were no surface washings to complicate our results. These results may be seen by reference to the analyses made of the water of Angle brook below Marlboro', of Sudbury river above and below Ashland, of Charles river above and below Holliston, and of Mill brook above and below Arlington.

The effect of large towns and cities, which have open drain

or pipe sewers, upon running streams is much greater than that of those which have only cesspool drainage. N. Beardmore, Esq., in evidence given before the "Royal Commission on Water Supply of London," considers the sewage from "all towns with above 3,000 inhabitants, or, in fact, all towns which choose to have pipe drainage," as dangerous, and says, "pipe drainage is an enemy to rivers."

The effect of pipe drainage upon river-water may be seen to a slight extent by the analysis of the Charles-river water above and below Milford, which town has a small sewer running through the principal street and emptying directly into the Charles. The contrast is not so great, however, as if the water above the town did not come from a very large and shallow mill pond (Cedar Swamp pond), the bottom of which was covered with a large amount of decaying vegetable matter, which accounts for the large amount of both free and "albuminoid" ammonia in the water above the town.

Filtration. — The effect of filtration upon a large scale is well shown in the case of the London water. From the report of the Water Commission above referred to (p. ci.), it appears that the filters not only remove the suspended matters, but also a very considerable amount of those which are dissolved, while the amount of oxygen in the water is sometimes increased.

The following table gives the amount of total dissolved material, organic and volatile, ammonia and oxygen in the water before and after filtration, as effected by the Thames, New River and East London companies : —

	GRAINS TO THE IMPERIAL GALLON.					
	THAMES CO.		NEW RIVER CO.		E. LONDON CO.	
	Before filtration.	After filtration.	Before filtration.	After filtration.	Before filtration.	After filtration.
Dissolved Matter	20.825	19.479	22.402	21.550	24.940	24.360
Organic and Volatile . . .	1.261	0.976	0.702	0.567	0.915	0.300
Dissolved Oxygen	0.796	0.825	0.906	0.906	0.891	0.752
Ammonia	0.003	0.002	0.001	0.001	0.004	0.003

The analyses of Wanklyn and Chapman, of the "Thames, near Hampton court, where the water companies take their supply," show a diminution in both the free and "albuminoid" ammonia after filtration, as follows:—

DATE.	PARTS PER 100,000.			
	BEFORE FILTRATION.		AFTER FILTRATION.	
	Free Ammonia.	"Albuminoid" Ammonia.	Free Ammonia.	"Albuminoid" Ammonia.
July, 1867 . . .	{ 0.0045 0.0015	0.028 0.023	0.0010	0.006
Sept. 1868 . . .	0.0020	0.022	0.0015	0.007

Thus, a very great reduction in the amount of organic matter is effected by filtering water through sand filter-beds, which are not overtaxed.

In reference to the removal of sewage contamination from water by filtration, we cannot rely upon it, although it would probably remove a large proportion of it. In the evidence before the Water Commission of London, we find the following testimony given by Dr. Frankland:—

Question. Will no system of filtration remove it (sewage) ?

Answer. I would not say that it is impossible to remove it, but no system of filtration will secure its removal. There are only two processes by which it can be effectually removed, the one is by boiling for a long time, and the other is by distillation ; and, therefore, it is that I say, that, inasmuch as those two processes are impracticable on a large scale, in my opinion water that has once been contaminated by sewage ought not afterwards to be used for domestic purposes.

Ques. Then, are we to understand you to say that no amount of filtration would render those waters fitted for the supply of the metropolis ?

Ans. As I have stated, no process of filtration that has hitherto been devised will remove choleraic dejections from water ; and, inasmuch as it is generally believed that the noxious matter of sewage exists there in the forms of minute germs, which are probably smaller than blood globules, I do not believe that filtration through a considerable stratum of chalk could be relied upon to free the water perfectly from such germs."

VI. OPPORTUNITIES FOR STORAGE.

There can be no doubt that both vegetable and animal impurities gradually disappear from water when exposed to the influence of light and air either in large lakes or running rivers, though the rapidity with which this process takes place has often been greatly exaggerated. Mr. S. F. Holmes, surveyor of Sheffield, says in answer to a question whether a certain water is at all colored with peaty matter : " It is, until it has been stored in the reservoirs. From thence the water runs down a conduit for some miles to the services, and it remains in some of them for three days before it is used and the coloring matter to a great extent is taken out.

Ques. How long does it take to precipitate the coloring matter ?

"*Ans.* I should think two or three days would do it, but it is not often that you can observe it in the town." ¹

Although the coloring matter in our river-water does not seem to disappear so readily as that of the water referred to in the above answers, yet there is no doubt of the beneficial effect of storage in this respect. The testimony of eminent chemists and hygienists bearing upon this subject has been given in another portion of this report, and need not therefore be repeated.

In this process of purification the organic substances are generally supposed to be oxidized and precipitated. It is, however, difficult to arrive at correct conclusions as to the effect of storage by an examination of the water of rivers and of the lakes into which they run, for a river may, from some temporary cause, bring very impure water into a lake to be there mixed with a large body of purer water brought to the lake either by the same river at a former time, or by other rivers, or by underground springs. The effects of storage in the purification of water will therefore be masked by the still greater effects of dilution. For this reason we have endeavored to make experiments where the effects of dilution could be excluded and the effects of light and air, as the active agents in purification by storage, could be studied separately. The details of this investigation will be found in Appendix B. Though owing to the small number of experiments no very positive conclusions are warranted, yet the results seem to indicate that oxidation plays a less important part in the purification of water by storage than has been sometimes supposed.

Whatever may be the nature of the process by which purification by storage is effected, there is no doubt that, in any scheme for supplying a large city with river-water for domestic use, storage basins are no less important for ensuring the purity, than as a means of regulating the quantity

¹ Evidence before Royal Commission on Water Supply of London.

of the water to be supplied. It must be borne in mind, however, that purification by storage can only be properly effected when the basins have a depth sufficient to prevent vegetable growth upon the bottom, for, in consequence of the growth, death and decay of vegetable substances, the water of shallow basins is found to deteriorate instead of improving by storage. As instances of this sort of contamination may be mentioned the waters of Cedar Swamp pond and Whitehall pond and the water supplied to Arlington as compared with that of Mill brook. The analyses of these waters are to be found in Tables I., II. and IV., pages 43, 50 and 56.

It will be seen, therefore, that from a sanitary point of view, it is important to consider the size and depth of the proposed storage basins, in order to decide as to the relative merits of the various schemes for supplying the city with water.

PART SECOND.

DESCRIPTION OF RIVERS.

Sources of Information.

The sources from which we have obtained information to enable us to judge of the relative merits of the four rivers in question may be classified as follows: —

I. PERSONAL INSPECTION OF THE RIVERS AT VARIOUS POINTS OF THEIR COURSE.

This inspection was made by the whole committee, accompanied by the City Engineer, Mr. Davis, or by the resident Engineer, Mr. Fteley. Ten days were thus devoted to excursions to the different drainage areas, in the course of which the color, taste and general appearance of the water were

determined at many different points on the rivers and their tributaries. The most important sources of pollution, and their effect upon the character of the river-water, were also noted.

II. REPORTS FROM THE ENGINEER'S OFFICE.

The City Engineer has at our request caused a list to be prepared giving the number and character of the manufacturing establishments situated on the various rivers and their tributaries, and also those situated within the various watersheds, though not upon the streams, and consequently not using water-power. We have also received from the same source an approximate estimate of the population in the various water-sheds and the ratio of the population to the drainage area. These documents will be found in Appendix A.

For our further guidance in this matter, an opinion has been given by an engineer on the possibility of diverting the sewage of the principal towns in the different drainage areas from their respective rivers, in case these rivers should be chosen as a source of water-supply; but as this opinion does not rest on actual surveys, it is not offered for publication.

III. CHEMICAL ANALYSIS.

Thirty-five samples of water collected either on the excursions above alluded to or subsequently, at points indicated by us, by a competent member of the Water Department, were subjected to analysis in the chemical laboratory of the Harvard Medical School. The results are given in tabular form in a subsequent portion of the report.

IV. COLLECTION OF TESTIMONY, SPECIFIC AND GENERAL.

Besides consulting various reports of committees and testimony of experts all bearing upon the general question: "What constitutes wholesome water for domestic use?" we have, wherever it seemed desirable, endeavored to obtain the

testimony of intelligent persons in the habit of using the water of the various rivers under consideration, and competent to give impartial testimony as to the effect of such use.

SUDBURY RIVER.

Color, Taste, and general Appearance. — The water of this river, owing apparently to the meadow land through which it flows in the upper portion of its course, has usually in the summer and autumn a brownish-yellow color. At the time of our visit, in the early part of September, this color was quite deep, our observations in this respect confirming those of Prof. Nichols as given in his report, "On the Present Condition of certain Rivers of Massachusetts." (City Doc. 138, 1874, p. 102.)

The taste of the water differed at different points of the river, being generally of a more or less earthy character. Below the Cordaville Wool Factory the water had a decidedly oily taste.

Sources of Pollution. — 1. Sewage. The following towns are on or near the streams, and must affect their character more or less: Marlboro' (pop. 1870, 8,474), Westboro' (3,601), Ashland (2,186), Framingham (4,968), Hopkinton (4,419), and Southboro' (2,135). Total population of above towns 25,783; total population, excluding Framingham, whose inhabited territory is mostly outside the area determined by the proposed location of lowest dam, 20,815. Total population of drainage area, estimated, at engineers' office, for fractions of towns lying partly within and partly without the area, 16,722.

Although none of these towns is sewered, yet the discharge of sewage from them into the streams is in some instances practically direct and injurious. Marlboro' is a growing town, has a high situation, and consequently rapid slopes. Angle-brook, below the town, shows distinct pollu-

tion, by chemical analysis (see Analyses Table I., No. 20). Westboro' has in prospect a water-supply, but has no sewers. These, however, must follow as a matter of course, and the result will be directly injurious if the sewage be not diverted. Ashland is for the most part low and springy. Its soil is to a great extent sandy and gravelly. Its natural drainage is excellent, and therefore injurious to the Sudbury, which here receives at first hand the discharges of numerous privies, pigsties and kitchen sinks from houses situated on the banks. Hopkinton is very high, its land springy, the highest portions seeming to have as much surface moisture as the low lands. This is a condition which drainage would relieve at the expense of the tributaries, and which even now is favorable to a rapid transfer of sewage to the streams. The influence of South Framingham upon Farm pond is very little at the present day, but will probably increase from year to year, and is therefore worthy of attention.

2. Manufacturing refuse. There are about twenty-five manufacturing establishments on the Sudbury and tributaries. Subdividing these somewhat according to the nature of the works, we have,—

Woollen and shoddy mills	.	.	.	.	.	3
Batting and twine	.	.	.	.	.	2
Print-works (not yet started)	.	.	.	.	.	1
Boot and shoe	.	.	.	.	.	1
Saw-mills	.	.	.	.	.	7
Emery mills	.	.	.	.	.	2
Machine shop	.	.	.	.	.	1
Plaster mills	.	.	.	.	.	4
Grist mills	.	.	.	.	.	9

Total, 30 industries and 220 employés, of which the woollen, shoddy and batting mills employ 128, and the boot and shoe, 30.

There are about fifty-two establishments not using water-power and situated more or less distant from the water-courses. Of these, the gasworks at Marlboro' are not yet started. Six are straw factories at Westboro' and thirty-six are boot and shoe factories. At South Framingham a hat factory discharges its drain upon the margin of Farm pond. The water in this sewer at the date of our visit, Sept. 3, was opaque, filthy, and stagnant. On the same day the Sudbury at Cordaville, below the wool factory, was in a very dirty state, — turbid, with masses of filth floating upon the surface, — and had an oily and otherwise disagreeable taste. The weeds along the margin were discolored. The mill was in operation.

In order to purify the Sudbury for drinking purposes, not only should the several specific nuisances be wholly abated, but whole towns must, sooner or later, come under radical treatment. The same is of course true of the other streams in question. As to the possibility of diversion, this is still to be decided for the several towns by more accurate inspections and surveys than have yet been made. It has been suggested, from an examination of the general features of the country, that Marlboro' sewage may be diverted through Hop, Wash and Landham brooks to the Sudbury at Wayland, a point below where it has been proposed to take this water; that Westboro' may be sewered into the Assabet by the way of Little Chauncy pond and Stirrup brook; that it is practicable to divert the sewage of Ashland to the Sudbury at a point below the city dams. The natural drainage of the central part of Framingham is into the Sudbury below the proposed dams, and the natural drainage of South Framingham is into Beaver Dam brook, a tributary of Lake Cochituate. It is considered possible to divert the South Framingham sewage into Sudbury river below the proposed dams. An exceedingly small part of South Framingham now drains into Farm pond, but this may be diverted in either of two ways.

Density of Population. — Statements in regard to the den-

sity of the population in the Sudbury-river valley, and its probable future increase, being only of interest as affording a means of comparing this river with the other three, will be given in the third part of this report, which is devoted to a comparison of the four drainage areas under consideration.

Chemical Composition. — The worst portions of this river, as shown by the following series of analyses (Table I), are Whitehall pond, below a wool factory in Cordaville, above and below Ashland, and Angle brook just below Marlboro'.

TABLE I.—Sudbury River—[Parts per 100,000.]

Number.	Date.	LOCALITY.	Free Ammonia.	"Albuminoid" Ammonia.	Inorganic.	Organic and Volatile.	Total Residue.	Chlorine.
18	Sept. 24	Whitehall pond	0.0106	0.0248	2.0	2.6	4.6	0.30
19	" 24	Cold Spring brook (Basin No. IV.) . .	0.0052	0.0150	3.8	1.8	5.6	0.50
20	" 25	Angle brook below Marlboro'	0.0016	0.0104	7.6	5.4	13.0	2.70
21	" 25	Angle brook at Dam No. VII.	0.0010	0.0090	4.6	2.4	7.0	0.70
22	" 25	Stony brook at Dam No. III.	0.0010	0.0190	3.8	3.0	6.8	0.50
23	" 24	Sudbury river at Cordaville ¹	0.0090	0.0270	3.6	3.8	7.4	0.45
24	" 5	Sudbury river above Ashland	0.0020	0.0310	4.2	1.8	6.0	0.80
25	" 5	Sudbury river below Ashland	0.0034	0.0360	4.8	3.4	8.2	1.20
26	Oct. 2	Sudbury river ²	0.0016	0.0290	3.6	3.8	7.4	0.80

¹ Sample taken just below the wool factory.

² Exact locality unknown. Collected by Mr. Fteley for experiments on storage.

Whitehall pond is a shallow pond, which contains a large amount of vegetable matter partially in a state of decomposition, so that a large amount of both the free and "albuminoid" ammonia was detected in its water.

The water from below the wool factory at Cordaville was collected at our request, for the purpose of observing the effect of the factory upon the water. At the time of our visit

the river at this point was extremely filthy, but the specimen collected for analysis had a much better appearance. It does, however, contain too large an amount of free and "albuminoid" ammonia.

The specimens taken above and below Ashland were from points in the river but a short distance apart, yet the alteration in the chemical composition is quite decided. This is easily explained, by the fact that between these two points are numerous pig-pens, sink-drains and privies situated directly on the edge of the water.

In the water of Angle brook, just below the town of Marlboro', we find a large amount of solids, both organic and volatile, and inorganic, and a comparatively large amount of chlorine. This can only be explained by the fact that it must receive, above the point from which the sample was collected, the drainage from Marlboro', since about a mile and a half lower down, at the point of the proposed location of dam No. VII., the amount of these substances is much diminished, owing to the dilution which has taken place, and to the fact that there are no sources of pollution between the two points.

With these exceptions, which can be accounted for by the circumstances in each case, the water has an excellent composition.

The water of Stony brook, at the point of the proposed location of dam No. III., has a hardness of 1° of the English scale.

Opportunities for Storage. — The proposed storage basins on the Sudbury river are seven in number, besides Whitehall and Farm ponds. Some of these basins are situated on the Sudbury river itself, and others on its principal tributary, Stony brook. Owing to the way in which basins II. and III. are to be connected with the gate-chamber of dam No. I., it will be possible to draw the water from either branch of the

stream at pleasure.¹ This is to be regarded as a decided advantage, for in case the water of one branch or basin shall, from any local cause, become impure, it will be possible to give this water the benefit of prolonged storage, while the other branch is used as a source of supply.

In concluding this description of the Sudbury river, it may be well to allude to certain rumors affecting the character of this stream as a source of water-supply. The City Engineer, in his report on an additional water-supply (City Doc. No. 38, 1874, p. 25), quotes the statement of Mr. Loammi Baldwin, made in 1834, to the effect that the water of the Concord and Sudbury rivers possesses some poisonous quality in consequence of which "the workmen obliged to labor in the water complained that it made their hands and feet sore, and if a little scratch occurred to their flesh, or the skin was torn or bruised away, the water would cause it to fester into a serious wound, and it was often necessary to suspend working in it, that the sore might heal."

On the other hand, Mr. Caleb Eddy, Agent for the Middlesex Canal Corporation, writing in 1843, says: "An idle story has been circulated in regard to the water of Concord river containing some deleterious substance which would cause a wound by contact with it, to 'fester' or become greatly irritated. . . . Carpenters, and other mechanics, who have been constantly employed on the works of the canal, and who have been a great many times in the water during the past thirty years, have experienced no such trouble, having daily washed in and otherwise used it."

The portion of the river referred to in these reports is below the point from which water is to be taken in the proposed scheme, and is doubtless liable to receive, at certain seasons of the year, a considerable amount of decaying vegetable matter from the extensive meadows between Wayland and Billerica, though it is highly improbable that water thus

¹ See City Doc. No. 29, 1873, p. 36.

contaminated could produce the injurious effects above alluded to. Against the character of the water in that portion of the river which constitutes the proposed source of supply similar charges have, as far as we are aware, never been made, and our inquiries on this subject have failed to elicit any evidence that the water of this part of the stream can produce any injurious effects upon persons using it.

It has been asserted, however, that the high rate of mortality in the City of Boston during the year 1872 proves the unwholesomeness of the Sudbury-river water, which during a few months of that year was diverted into Lake Cochituate to supply the want created by a prolonged drought.

An examination of the following table, giving the deaths in Boston from various diseases, for the years 1871 and 1872, proves this statement to be without foundation : —

Deaths from Various Diseases in 1871 and 1872.

DISEASE.		1871.	1872.	Percentage Increase.
<i>Diseases Affected by Water.</i>	Cholera Morbus	31	35	12.9
	Diarrhoea	139	173	24.5
	Dysentery	56	56	0
	Typhoid Fever	172	229	30.1
	Total	402	493	22.6
<i>Diseases not Affected by Water.</i>	Small-Pox	23	733	3109.
	Diseases of Brain	236	368	56.
	Cholera Infantum	526	742	41.
	Scarlet Fever	111	258	132.
	Pneumonia	345	517	50.
	Total deaths in city	5,888	8,090	37.4

It will be seen that, though the total number of deaths in the city was 37.4 per cent. greater in 1872 than in 1871, yet the percentage increase of those diseases which *may* be pro-

duced by impure drinking-water, was less than that of diseases supposed not to be so produced. In other words, though the death-rate in the city was remarkably high in 1872, this great mortality cannot justly be attributed to any unusual impurity of the drinking-water.

CHARLES RIVER.

In considering the relative desirability of this river as a source of water-supply, we have assumed, as a basis of comparison, that the river is to be dammed one mile above South Natick, and the water taken directly from the basin thus formed. Against the construction of the other proposed basin in the neighborhood of Dedham are to be urged, not only the grave objections mentioned by Mr. Fteley in his report (City Doc. No. 85, p. 124), but also the fact that the proposed system of sewers for the growing town of Natick, to be constructed for the purpose of preserving Lake Cochituate from pollution,¹ will empty into the Charles, in the neighborhood of South Natick, and thus render it undesirable to take the water from any point lower down the river.

Color, Taste and general Appearance. — The water of this river was at the time of our visit rather less colored than that of the Sudbury. The taste was generally somewhat earthy. Below Holliston a slightly bitter taste was noticed, and the appearance of the river bottom in this town indicated the presence of decomposing organic matter.

Sources of Pollution. — 1. Sewage. The following towns are wholly or partly within the area: Bellingham (pop., 1870, 1,283), Dover (645), Franklin (2,512), Holliston (3,073), Medway (3,721), Medfield (1,142), Milford (9,890), Norfolk (1,081), Hopkinton (4,421), Sherborn (1,062), Wrentham (2,292). Total population of above towns, 31,122. Total population of drainage area (estimated for fractional

¹ See order passed in Common Council, Oct. 22, 1874, and Mr. Fteley's report on the Sewerage of Natick (City Doc. No. 85, 1874, p. 57).

parts of towns not wholly within the area), 25,149. The towns below the proposed location of the dam at South Natick are not included in the above statement.

Bellingham has a gravelly soil. A cemetery here drains into a small tributary of the Charles. Holliston, a growing town, drains into the outlet of Winthrop pond. At Holliston Centre the stream is sluggish and filthy, has numerous privies in its immediate vicinity, and receives in a very direct manner, by ditches cut upon the steep slopes, the whole drainage of this part of the town. The diversion of the drainage of Holliston offers serious practical difficulties. Medway village is directly on the bank of the river. West Medway is scattered; has surface drainage; no sewers. Chicken brook runs through the edge only of the populated district. A cemetery lies near the banks of the stream. Milford is the most important town on the Charles. Its population to-day is about 11,000. It already has a sewer, on Central street, leading down to the river. All drainage at Milford goes into the Charles. There are numerous privies along the stream. The plan is suggested of diverting the sewage into the Blackstone river. Cedar Swamp pond, just above Milford, was, at the time of our visit, an extensive flat of soft, boggy mud, through which meandered a comparatively narrow stream. This would seem to be a fruitful source of the products of vegetable decomposition. It is considered quite practicable to divert the sewage of Medfield *via* Mill brook into the Neponset river. South Natick drains into the Charles, but below the site of the proposed dam. The question of diversion of sewage in some of these cases is not easily answered.

2. Manufacturing refuse. Total number of factories using water power on the Charles river and tributaries, 66. Total number of employés, 884.

Classification of 66 mills on the Charles river and its tributaries :—

Woollen and shoddy mills	10
Paper mills	4
Cotton, thread and batting	6
Felting mills	2
Saw mills	26
Grist mills	9
Machine, nail, knife, etc.	7
Carriage, wheelwright and cabinet	4
Paint, bonnet-frame, leather board, cement, brick, each 1	5

A difference will be found in the sums total, owing to a certain amount of subdivision.

Total number of employés in the woollen, shoddy, felting, paper, batting, cotton and thread mills using water-power, about 700.

Total number of factories on the Charles-river drainage area, 139.

Chemical Composition.—It will be seen, by an examination of the following analyses of Charles river [Table II.], that the worst portions at the time of our visit were Mine brook, and those portions above and below the towns of Milford and Holliston.

TABLE II.—Charles River—[Parts per 100,000].

Number.	Date.	LOCALITY.	Free Ammonia.	"Albuminoid" Ammonia.	Inorganic.	Organic and Volatile.	Total Residue.	Chlorine.
1	Sept. 7	Winthrop pond above Holliston . .	0.0080	0.0230	2.6	3.0	5.6	1.00
2	" 7	Jar brook below Holliston	0.0100	0.0420	2.6	3.0	5.6	1.75
3	" 7	Cedar Swamp pond above Milford . .	0.0180	0.0240	2.6	2.2	4.8	0.80
4	" 7	Charles river below Milford ¹	0.0026	0.0220	7.4	5.0	12.4	3.00
5	" 7	Mine brook near source	0.0054	0.0320	3.0	3.8	6.8	0.60
6	" 9	Mine brook near mouth	0.0026	0.0350	4.0	2.8	6.8	0.50
7	" 9	Chicken brook ²	0.0000	0.0200	4.2	3.2	7.4	1.00
8	" 9	Mill river near mouth ³	0.0026	0.0160	2.4	2.2	4.6	0.50
9	" 9	Charles river at Rockville	0.0026	0.0230	2.8	2.8	5.6	0.40
10	" 9	Stop river near mouth ⁴	0.0026	0.0160	5.0	2.0	7.0	0.50
11	" 12	Charles river at Dearth's Bridge ⁵ . .	0.0026	0.0270	2.6	3.0	5.6	0.40
12	" 12	Boggistow brook ⁶	0.0040	0.0160	3.6	3.0	6.6	0.60
13	" 12	Charles river above South Natick . .	0.0026	0.0230	2.6	3.0	5.6	0.80
14	" 12	Charles river below South Natick . .	0.0026	0.0220	3.0	2.4	5.4	1.00
15	" 14	Charles river above Dedham	0.0010	0.0168	2.0	3.2	5.2	0.40
16	" 14	Mother brook below Dedham	0.0016	0.0176	3.8	2.2	6.0	0.55
17	" 14	Charles river at Newton Upper Falls	0.0026	0.0185	3.0	3.4	6.4	0.70

¹ Collected at Howard's bridge.² At mouth of brook just below W. Medway.³ In Norfolk.⁴ In a portion of the proposed Basin.⁵ Below Medfield.⁶ About two miles from mouth in Medway.

The dirty condition of Mine brook near its source was probably due to the fact, that the specimen was collected at a time when a mill pond just above the point of collection was being scoured. At this point is a felt mill, and still farther down the brook is a shoddy mill, two of the most objectional kinds of manufactories.

The water above Milford, in Cedar Swamp pond, was at the

time of our visit very low, and the bottom of the pond was covered with a large amount of vegetable material, which was partially in a state of decomposition. This accounts for the large amount of free and "albuminoid" ammonia obtained upon analysis. Below Milford the specimen was collected at some distance below the opening of the sewer, so that there was a good opportunity for the sewage to be diluted, and for the free ammonia to escape by volatilization; yet the amount of "organic and volatile" and chlorine was much greater than in any other portion of the river examined.

The water from above Holliston was collected from Winthrop pond, which is a shallow pond and contains much vegetable matter. The bottom was not, however, exposed to the same extent, and decomposition was not as evident as in the case of Cedar Swamp pond. In the water below Holliston we find an increase of the free and "albuminoid" ammonia and chlorine, showing the probable addition of sewage matter during its passage through the town, where to external appearances it was extremely filthy.

The hardness of the Charles-river water at Rockville, at the head of the proposed basin, is 1°, the same as that of Sudbury river.

Opportunities for Storage. — The storage of water in the Charles-river scheme for water-supply is to be effected in one large basin. This is to a certain degree disadvantageous, for a local source of pollution will in this case necessarily affect the whole supply of water, whereas in a scheme providing for numerous smaller storage basins it will often be possible to store the impure water until it shall have time to purify itself. On the other hand, a single large storage basin is, other things being equal, less likely to have shallow flowage than a series of small ones, since the length of water line in proportion to the water area will be greater in the latter than in the former.

MYSTIC RIVER.

Color, Taste, and general Appearance. — At the time of our visit to the Mystic river the water was, as far as the brownish-yellow color was concerned not very different from that of the Charles. Several tributaries of this river, however, owing to sources of pollution described below, had a color, odor, and taste that were in the highest degree objectionable.

Sources of Pollution. — 1. Sewage. The principal towns are Stoneham (pop., 1870, 4,513), Winchester (2,645), and Woburn (8,560). Total population of towns, 15,718. Total population of drainage area, 16,935.

The area is small and the towns compact and undrained. A cemetery was noticed lying close upon the little stream which crosses High street, in Stoneham, and empties into the Abajonna. Winchester pond is shallow and full of tufts of aquatic plants, suggesting a probably large amount of vegetable decomposition. The water of Wedge pond was greenish and turbid when visited. Woburn is rocky, undulating, and everywhere springy. It is supplied with water filtered from Horn pond or its immediate vicinity.

2. Manufacturing refuse. Factories on the tributaries of Mystic pond, 55, viz. : —

Tanneries and currying shops	.	.	.	.	.	26
Glue stock factory	.	.	.	.	.	1
Glue factories	.	.	.	.	.	2
Wool scouring establishment	.	.	.	.	.	1
Gas-works	.	.	.	.	.	1
Shoe factories	.	.	.	.	.	14
Inner sole and stiffening works	.	.	.	.	.	2
Saw-mills	.	.	.	.	.	4
Sash-factory	.	.	.	.	.	1
Grist, saw-factory, watch-hand, ropewalk, each	1,					4

Total industries, 56 ; employés, 2,975.

The 26 tanneries and currying-shops finish 11,325 hides per week; and the number of employés is 1,737.

Factories within the Mystic water-shed, not on the streams, 27; employés, 497.

Total number of factories in the Mystic drainage area, 82. Total employés, 3,472.

There are twelve tanneries on Russell's brook, which is thereby converted into a sewer of the most offensive description, notwithstanding the amount and flow of the water. Cummings' brook, before it joins Kendall's brook, is a still larger stream, and quite as rapid. It was exceedingly offensive to sight and smell when visited, and the air around had a strong odor of putrid animal matter, recalling the previous visit to the beaming-room. The mill-pond above Cummings' factory was fouled and blackened by the refuse of a morocco factory, and the bottom and sides of this pond, as well as of the stream below, were everywhere coated with an offensive black mud. A small stream, half a mile long, near Cummings' brook, and like it, an affluent of Horn pond, received the waste of two tanneries, and was also black and highly offensive.

Thus, from the dense population the sewage, and from the tanneries a large amount of decomposing animal matter, are turned into the Abajonna, and the Horn-pond branch, to be conveyed, not all, but inevitably some of it, to Mystic pond. And, judging by the past, the amount of pollution will increase from year to year, and with it the difficulty of the problem of purification. To leave matters as they are is to confidently expect in time a degree of contamination which will make itself felt in East Boston, Charlestown, Chelsea and Somerville, if it be not already felt in those communities. It may be that their statistics of mortality of to-day compare favorably with those of the well-water period, but it is questionable if the figures of the future will compare favorably with those of to-day. Of course, the only remedy

is to keep all this filth out by perfect sewerage. (See report of Mystic Water Board on this subject, City Doc. No. 94.)

Chemical Composition. — There are so many sources of pollution upon the banks of this proposed source of water-supply, both of the nature of objectionable kinds of manufactories, and of a thickly settled population, that the chemical analysis of the majority of the specimens [Table III.] showed a very dirty condition.

TABLE III.—Mystic River—[Parts per 100,000].

Number.	Date.	LOCALITY.	Free Ammonia.	"Albuminoid" Ammonia.	Inorganic.	Organic and Volatile.	Total Residue.	Chlorine.
27	Sept. 17	Abajonna River, above Burbank's pond	0.0080	0.016	8.0	4.0	12.0	1.8
28	" 17	Cummings' Brook, ¹ Unfiltered . .	0.1330	0.050	10.4	18.0	28.4	10.4
		" " Filtered . .	0.1330	0.028	9.0	16.4	25.4	10.4
29	" 17	Russell's Brook, ² Unfiltered . . . . .	...	...	586.2	76.6	662.8	346.0
		" " Filtered	2.6660	0.240	595.0	53.8	648.8	346.0
30	" 27	Abajonna River, above Mystic Lake	0.0080	0.023	8.0	7.2	15.2	4.1
31	" 17	Mystic Lake at Gate House . . .	0.0084	0.023	5.0	9.4	14.4	2.6
35	Oct. 26	Abajonna River, above Chemical Works in North Woburn . . .	0.0010	0.011	3.0	2.4	5.4	0.8

¹ Below Cummings' tannery.

² On Main St., near the ice-house track, below all the tanneries.

The sample (No. 35) collected at the head of the Abajonna, above all sources of pollution, has a composition as good as that of any of the other streams; but a short distance lower down, at a point just above Burbank's pond, the amount of impurities is nearly doubled.

During the analysis of the Cummings'-brook specimen, which was collected a short distance below Cummings' tan-

nery, at a time when there was a large amount of water running, the atmosphere of the laboratory was pervaded with an odor reminding one strongly of a piggery. In both this specimen and that collected from Russell's brook, below all the tanneries, there was a very large amount of sediment, and a strong odor of sulphuretted hydrogen, the amount of which, however, was not determined. The amount of suspended matter in the water of Cummings' brook was three, and in that of Russell's brook fourteen parts in 100,000.

The analysis of the water taken from the surface of Mystic pond at the gate-house shows that the impurities, which have been added between Burbank's pond and the lake, have, by no means, entirely disappeared from the water during its passage down the stream and through the lake.

The hardness of the water, at the gate-house, is two and one-half degrees, while that of the water at the very source of the Abajonna, above Eaton's Chemical Works, in North Woburn (No. 35, Table III.), is only one degree, the same as that of the other rivers. This difference must be caused by inorganic impurities added to the river between this point and the lake.

Mill brook flows through Arlington and empties into the Lower Mystic. Its composition is, therefore, only of importance in reference to the proposed use of this basin as an additional storage reservoir.

The water of this brook above the Arlington reservoir has a good composition [Table IV.], although the amount of organic and volatile is quite large. In passing through the reservoir, which is quite shallow, instead of being rendered purer, it receives a considerable amount of vegetable material, as shown by the decided increase of "albuminoid" ammonia in the water drawn from a faucet in Arlington. The water in the reservoir, at the time of our visit, as well as that drawn from the faucet, was very turbid.

TABLE IV. — Mill Brook — [Parts in 100,000].

Number.	Date.	LOCALITY.	Free Ammonia.	"Albuminoid" Ammonia.	Inorganic.	Organic and Volatile.	Total Residue.	Chlorine.
32	Sept. 25	Above the Arlington Reservoir . . .	0.0026	0.0066	5.0	5.4	10.4	1.10
33	" 25	From faucet in Arlington	0.0016	0.0240	4.4	4.4	8.8	0.90
34	" 25	Below Arlington Gas House	0.0530	0.0200	4.2	4.8	9.0	1.20

The water of the brook, during its passage through the town, receives an addition of free ammonia and chlorine from the town drainage, which would render its direct admission into a storage reservoir undesirable.

The hardness of the water above the reservoir is two degrees, being one degree harder than the water of the other rivers.

Opportunities for Storage. — In the scheme for supplying the city with the water of the Mystic river storage is to be effected in six artificial and two natural basins. This gives a very extended water line in proportion to the water area, resulting, as will be seen, in a large amount of shallow flowage.

SHAWSHINE RIVER.

Color, Taste, and general Appearance. — The water of the Shawshine was, at the time of our visit, rather less colored than that of any of the other rivers, and the taste seemed to us correspondingly pure.

Sources of Pollution. — 1. Sewage. The principal towns are Bedford (pop., 1870, 849), Billerica (1,833), Burlington (626), and Lexington (2,277). Total population of above towns, 5,585. Total population, omitting Billerica, whose populated district is mostly on the Concord river, 3,752. Total population of Shawshine drainage area, 2,691. Lex-

ington is the town of chief importance in the present connection. It has no drainage. The town can be drained, it is said, into Charles river by way of Clematis brook. The population of the other towns is scattered, and so situated as not greatly to affect the character of the water.

2. Manufacturing refuse. Factories upon the streams, 4; Employés, 22. A block-printing establishment at Burlington has 16 employés. The other establishments are saw, grist, planing and cider mills.

Chemical Composition. — The chemical composition of the water of the Shawshine river, as may be seen by the following table [Table V.], is unobjectionable, but it is no better than that of the head waters of the Sudbury, and but little better than that of those head waters of the Charles on which there are no sources of pollution.

TABLE V.—Shawshine River—[Parts per 100,000].

Number.	Date.	LOCALITY.	Free Ammonia.	"Albuminoid" Ammonia.	Inorganic.	Organic and Volatile.	Total Residue.	Chlorine.
35	Sept. 22	At the old Middlesex Canal ¹	0.002	0.012	4.4	2.4	6.8	0.50
36	" 22	West branch ²	0.004	0.016	5.0	2.6	7.6	0.50
37	" 22	Vine brook ³	0.000	0.012	5.0	2.2	7.2	0.60

¹ At the proposed location of the dam of basin No. I.

² At the western apex of proposed basin No. II.

³ At the eastern apex of proposed basin No. II.

The hardness of the water of the Shawshine at the old Middlesex canal is 1°, the same as that of the Charles and Sudbury.

Opportunities for Storage. — The proposed storage basins on the Shawshine river are three in number, holding in the aggregate 3,300,000,000 gallons. How these storage facilities compare with those of the other rivers will be considered in the third part of this report.

PART THIRD.

COMPARISON OF RIVERS.

COLOR, TASTE AND GENERAL APPEARANCE.

A superficial examination of the color, taste and general appearance of the water, such as we were able to make at the time of our visit to the different streams, showed that in these respects the rivers in question differed very decidedly from each other. The brownish-yellow color, which all the rivers possessed in a greater or less degree, was most marked in the Sudbury and least perceptible in the Shawshine river. The Mystic and the Charles did not differ greatly from each other in this respect, the slight difference between them being in favor of the Mystic. In regard, therefore, to the brownish-yellow color, taken as an evidence of the presence of organic matter of vegetable origin, the rivers were, at the time of our visits, to be preferred in the following order: —

SHAWSHINE,
MYSTIC,
CHARLES,
SUDBURY.

As this order is exactly the inverse of that in which the rivers were visited, and as our excursions extended over a period of twenty-four days, during which little or no rain fell, it seemed probable that the observed difference of color might depend to some extent upon the time of the observation, or, in other words, that all the rivers might have been growing gradually less and less colored during the time occupied by our excursions, and that, had they been visited in the opposite order, their relative depth of color might also have been inverted. To decide this question a sample of water was collected at our request on the same day, Nov. 17th, 1874,

from each of the four different rivers. The points chosen for the collection of these samples were, on the Sudbury river just above the present dam, on the Charles at South Natick, on the Abajonna at Cross street, Winchester, and on the Shawshine at the crossing of the Telegraph road.

The samples thus collected were all of them less colored than the water of corresponding points, as observed at the time of our visits, which is readily accounted for by the prolonged drought which had prevailed. The difference between the four samples in respect to color was very slight, but by careful comparison their order was determined as follows : —

MYSTIC,
SHAWSHINE,
CHARLES,
SUDBURY,

the Sudbury being the most highly colored. This order differs from that obtained by the comparison of the former observations only in the relative position of the Mystic and Shawshine rivers. It seems, therefore, very probable that the waters of the Charles and Sudbury are as a rule more highly colored than those of the other two rivers, and that of the Charles and Sudbury the latter is the more deeply colored of the two.

This *brownish-yellow* color is, however, not the only point to be regarded in considering the general appearance of river-water.

Several tributaries of the Mystic river are, as above stated, polluted to such a degree by the refuse from tanneries and other manufacturing establishments, that they are extremely offensive to sight and smell. Taking this fact into consideration the Mystic is decidedly the least desirable stream, and the four rivers are, in regard to color, taste and general appearance, to be preferred in the following order : —

SHAWSHINE,
CHARLES,
SUDBURY,
MYSTIC.

SOURCES OF POLLUTION.

Sewage. — None of the four streams in question receives a large amount of direct sewage contamination, yet all furnish special instances of a more or less objectionable character. Among the most obvious of these are the sewer at Milford and the ditches at Holliston. Equally obvious and direct and not less objectionable in the aggregate are the numerous privies which overhang the streams in various localities. But the more direct the pollution the more definite the remedy; and as nearly all the towns are undrained, and as a diversion of direct sewage is a *sine quâ non* in the case of any river selected as a source of water-supply, the comparative amounts of probable pollution of the several rivers may be fairly inferred from the relative density of population of the respective drainage areas, a subject which is treated elsewhere in this report.

Manufacturing Refuse. — In comparing the four streams on the basis of relative pollution by manufacturing refuse, we have consulted the State reports of statistics of industries for 1845, 1855 and 1865 (the latest), and have availed ourselves of information as to the number and kind of manufacturing establishments in the several drainage areas in 1874, kindly furnished, at our request, from the Engineer's office. The latter information, obtained by personal inspection, is, from the mode of its collection, less exhaustive than State reports, and cannot, therefore, be directly compared with them in the same tables, while, as coming from an independent source and bearing a later date, it has a value of its own. The State reports, on the other hand, are defective,

especially in the returns of number of works and employés, and for comparison on a small scale, as between towns and towns, would be likely to mislead in these particulars ; while the sums total for whole collections of towns by drainage areas seem more worthy of comparison as holding a balance of errors. The State returns are more complete and uniform in the matter of values of manufactured products than in any other item, and for this reason a separate comparison has been made on this basis.

The value of such returns in the question before us, aside from their numerical correctness, is in proportion to the uniformity of their relation to the quantity and quality of refuse material, and of the relation of these to the several waters under consideration. If a single cotton factory on the Charles turns its refuse directly into the stream, while another on the Sudbury utilizes its waste material by irrigation, or if the one is situated directly on the stream and is run by water-power, while the other, run by steam, is situated at some distance from the water-courses, then, it is obvious, a comparison of the values of the manufactured products of the two establishments will not indicate their relative polluting effect upon the respective waters. But the need of water, not only for power, but for the various processes of manufacture in a large proportion of works having liquid refuse, approximates these to the water-courses, and the comparison which might mislead in detail would, when applied to whole river-basins, fairly indicate the order of preference.

We are of the opinion that the returns as to number of works are sufficiently accurate to determine the order of preference, but not precise rates of growth, while as to valuation of products there is sufficient uniformity to determine both relative amounts and percentage rates of increase as nearly as the subject demands.

Synopsis of information concerning manufactures, by drainage areas.

1. Collected from State reports : —

(a.) Number of establishments.

(aa.) Including Framingham and Billerica.

In 1845, 1855, and 1865.

(bb.) Omitting Framingham and Billerica.

In 1845, 1855, and 1865.

(b.) Value of manufactured products.

(aa.) Including Framingham and Billerica.

In 1845, 1855, and 1865.

(bb.) Omitting Framingham and Billerica.

In 1845, 1855, and 1865.

2. Collected by personal inspection : —

(a.) Number of establishments.

In 1874.

In the tables which follow, the above data are given in figures representing the absolute amounts, and also the ratio per square mile, in each drainage area. Manufactured products are also reduced to four classes, and the absolute values of each and the ratio per square mile given for each drainage area. The first three of these classes are also collected into one large class, and the amounts and ratio given as in the other cases. The ratios per square mile in these tables have been reduced to nine diagrams on a system of rectangular lines, in order to present to the eye an easy and ready interpretation of the figures. Whoever, in looking at the diagrams, seeks for the ready indication of relative rates of growth in the ascending lines, should bear in mind that this is not here directly presented to the eye. Of two parallel ascending lines, for instance, the upper indicates the less percentage rate of increase.

Number of manufacturing establishments and ratio per square mile in the collective towns, including Framingham and Billerica, of the several drainage areas : —

In 1845 (State Report).

	Works.	Sq. Miles.	Ratio.
Sudbury	73	73	1.00
Mystic	40	28	1.43
Shawshine	23	34	0.68
Charles	122	152	0.80

In 1855 (State Report).

	Works.	Sq. Miles.	Ratio.
Sudbury	75	73	1.03
Mystic	116	28	4.14
Shawshine	22	34	0.65
Charles	146	152	0.96

In 1865 (State Report).

	Works.	Sq. Miles.	Ratio.
Sudbury	149	73	2.04
Mystic	102	28	3.64
Shawshine	45	34	1.32
Charles	230	152	1.51

Tabulating the results we have : —

	1845.	1855.	1865.
Shawshine	0.68	0.65	1.32
Charles	0.80	0.96	1.51
Sudbury	1.00	1.03	2.04
Mystic	1.43	4.14	3.64

(See Diagram I.)

Number of manufacturing establishments and ratio per square mile in the collective towns of the several drainage areas, omitting Framingham and Billerica, to compare with the table in which these two towns are included : —

In 1845 (State Report).

	Works.	Sq. Miles.	Ratio.
Sudbury	35	73	0.48
Mystic	40	28	1.43
Shawshine	8	34	0.24
Charles	122	152	0.80

In 1855 (State Report).

	Works.	Sq. Miles.	Ratio.
Sudbury	57	73	0.78
Mystic	116	28	4.14
Shawshine	15	34	0.44
Charles	146	152	0.96

In 1865 (State Report).

	Works.	Sq. Miles.	Ratio.
Sudbury	118	73	1.62
Mystic	102	28	3.64
Shawshine	23	34	0.82
Charles	230	152	1.51

In 1874 (Mr. Cunningham's Report).

	Works.	Sq. Miles.	Ratio.
Sudbury	77	73	1.05
Mystic	82	28	2.93
Shawshine	4	34	0.12
Charles	139	152	0.91

Tabulating the results we have : —

	1845.	1855.	1865.	1874.
Shawshine	0.24	0.44	0.82	0.12
Charles	0.80	0.96	1.51	0.91
Sudbury	0.43	0.78	1.62	1.05
Mystic	1.43	4.14	3.64	2.93

(See Diagram II.)

Value of total products of manufactures of towns wholly or partly within the respective drainage areas, collected from the State reports of industries for 1845, 1855 and 1865 : —

	1845.	1855.	1865.
Sudbury	\$1,310,015	\$1,400,072	\$7,399,501
Mystic	818,533	2,967,107	4,526,588
Shawshine	289,059	459,143	1,323,681
Charles	2,171,636	5,496,218	8,904,968

Value per Square Mile of Drainage Area.

Sudbury	17,945	60,275	101,363
Mystic	29,233	105,969	161,664
Shawshine	8,502	13,504	38,932
Charles	14,237	36,159	58,585

(See Diagram III.)

The above summary includes for the Sudbury, the towns of Ashland, Framingham, Hopkinton, Marlborough, Westborough and Southborough; for the Mystic, the towns of Stoneham, Winchester and Woburn; for the Shawshine, the towns of Billerica, Bedford, Burlington and Lexington; and for the Charles, the towns of Bellingham, Dover, Franklin, Holliston, Medway, Medfield, Milford, Sherborn, Hopkinton, and Wrentham.

Omitting from the Sudbury, Framingham, whose drainage is mostly below the proposed dams, and from the Shawshine, Billerica, whose factories are mostly on the Concord river, we have : —

	1845.	1855.	1865.
Sudbury	\$611,281	\$3,539,594	\$5,641,919
Mystic	818,533	2,967,107	4,526,588
Shawshine	105,965	131,416	129,531
Charles	2,171,636	5,496,218	8,904,968

Value per Square Mile of Drainage Area.

Sudbury	8,374	48,483	77,287
Mystic	29,233	105,969	161,664
Shawshine	3,117	3,865	3,810
Charles	14,287	86,159	58,585

(See Diagram IV.)

In order to estimate the comparative amounts of different kinds of manufacturing refuse in terms of the value of manufactures, the four following classes are arbitrarily assumed: —

1. Glue, tanning, currying, shoddy, woollen, felting, silk and paper works.
2. Cotton, batting, thread and twine factories.
3. Chemical, dye, print, bleach, paint, gas and soap works and breweries.
4. Straw bonnet and hat, boot and shoe, and all other works not elsewhere mentioned.

Framingham and Billerica are omitted in the following tables: —

		1845.	1855.	1865.
I.	{ Sudbury	\$8,875	\$142,600	\$99,500
	{ Mystic	291,392	1,140,345	1,995,301
	{ Shawshine . . . . .	.....	13,200	46,000
	{ Charles	177,064	127,698	557,802
II.	{ Sudbury	34,700	132,750	.....
	{ Mystic . . . . .	.....	.....	.....
	{ Shawshine . . . . .	.....	.....	.....
	{ Charles	329,905	425,068	215,600
III.	{ Sudbury . . . . .	.....	.....	5,800
	{ Mystic	9,000	501,700	447,806
	{ Shawshine	15,000	.....	.....
	{ Charles	425	26,320	17,232
IV.	{ Sudbury	567,736	3,264,244	5,536,619
	{ Mystic	518,141	1,325,062	2,083,481
	{ Shawshine	90,965	118,216	83,531
	{ Charles	1,664,242	4,917,132	8,114,334

Combining the first three classes:—

I, II, III.	{ Sudbury	43,575	275,350	105,300
	{ Mystic	300,392	1,642,045	2,443,107
	{ Shawshine	15,000	13,200	46,000
	{ Charles	507,394	579,086	790,634

Ratio per square mile:—

I.	{ Sudbury	122	1,953	1,363
	{ Mystic	10,407	40,727	71,261
	{ Shawshine . . . . .	.....	388	1,353
	{ Charles	1,165	840	3,670

(See Diagram V.)

II.	{ Sudbury	475	1,818	.....
	{ Mystic . . . . .	.....	.....	.....
	{ Shawshine . . . . .	.....	.....	.....
	{ Charles	2,170	2,797	1,418

(See Diagram VI.)

Ratio per square mile — *Continued.*

	1845.	1855.	1865.
III. { Sudbury . . . . .	.....	.....	79
{ Mystic	321	17,918	15,993
{ Shawshine	441	.....	.....
{ Charles	3	173	113

(See Diagram VII.)

IV. { Sudbury	7,777	44,716	75,844
{ Mystic	18,505	47,324	74,410
{ Shawshine	2,675	3,477	2,457
{ Charles	10,949	32,350	53,384

(See Diagram VIII.)

I, II, III. { Sudbury	597	3,772	1,442
{ Mystic	10,728	58,644	87,254
{ Shawshine	441	388	1,353
{ Charles	3,338	3,810	5,202

(See Diagram IX.)

Comparison of the different drainage areas on the basis of manufactures, drawn from the preceding data : —

1. By percentage of increase from 1845 to 1865.

	No. of Works.	Val. of Products.
Sudbury (including Framingham)	104	465
Mystic	155	453
Shawshine (including Billerica)	94	358
Charles	89	310

Placing these in the order of preference : —

CHARLES,	CHARLES,
SHAWSHINE,	SHAWSHINE,
SUDBURY,	MYSTIC,
MYSTIC.	SUDBURY.

If this table be correct, the Charles shows, in both respects, a less rate of gain than the Shawshine, and the Shawshine less than either the Sudbury or Mystic; the Mystic the greatest rate in number of works, and the Sudbury in value of products.

But as the reports from which these data are derived are more defective in number of manufacturing establishments than in valuation of manufactured products, and as a factory is a more fluctuating unit of measure than a dollar, the order of merit should be sought in the second column rather than the first.

2. Percentage of Increase from 1845 to 1855.

	No. of Works.	Val. of Products.
Sudbury (omitting Framingham)	233	823
Mystic	155	453
Shawshine (omitting Billerica)	242	22
Charles	89	310

Placing these in the order of preference:—

CHARLES,	SHAWSHINE,
MYSTIC,	CHARLES,
SUDBURY,	MYSTIC,
SHAWSHINE.	SUDBURY.

That is to say, the Charles, Mystic and Sudbury hold the same relation to each other in both respects, and are preferable in the order named; while the Shawshine shows the greatest rate of gain in number of establishments and least in value of products.

Although it is within the range of possibility that the position of the Shawshine in the two columns should be in accordance with the facts, especially as, being a region of small productive power, its percentage gain might be greatly in-

creased by a comparatively few new establishments, yet it is more probable that there was an omission in the returns of the number of works in 1845.

The rate of growth, however, is not the measure of polluting power, nor can we, for estimates of the future, wholly depend upon the continuance of a present rate. To decide the question practically it is necessary to consider first the densities, or ratios per square mile, in the several drainage areas; we may then estimate how far the probable future increase shall affect our decision where two regions under comparison happen to be in the same year very much alike.

We continue the comparison, therefore, by a reference to the diagrams.

No. I. shows the ratio, or average number, per square mile, of manufacturing establishments in each drainage area, including Framingham on the Sudbury and Billerica on the Shawshine.

It shows that the Mystic has had the greatest number, the Shawshine the least, and the Sudbury more than the Charles, in each of the three years on which the returns were made. It shows the most steady increase in the Charles area, the most rapid late increase in the Shawshine and Sudbury, and, at the same time, a slight falling off in the Mystic. It shows that the actual growth, comparing the Charles and the Sudbury, was at first greater in the Charles, afterwards greater in the Sudbury.

No. II. is the same in character as No. I., but by reason of the omission of Framingham and Billerica corresponds more closely to the actual drainage areas, although it may give a less correct idea of the growth of these portions of the State of which the drainage areas are, as it were, centres. It will be seen that the Sudbury and Shawshine are considerably affected by the omissions, as indicated by their lower positions in this diagram, and that, as compared with Diagram I., the relative positions of the Charles and the Sudbury in 1845 and

1855 are reversed, but again restored in 1865, though the difference is slight. In other words, the Sudbury, starting at a considerable disadvantage in 1845, was gaining on the Charles in 1855, and ahead in 1865.

Diagram III. represents the same territorial extent as No. I., substituting value of products for number of works. It will be observed that the relative positions of the four regions are the same throughout and the same as in No. I. The Mystic here shows no falling off in the latter decade, considered by itself.

Diagram IV. represents the same territorial extent as No. II., substituting value of products for number of works. The relative positions at the start and at the finish are the same as in No. II., and at the second and third periods are the same as in Nos. I. and III.

Diagrams V.—IX. represent the values of different classes of manufactures, elsewhere described. No. V. represents Class I. Here, in fact, we see the predominance of the tanneries of the Mystic over the textile and paper works of the other streams. The Charles is barely ahead of the Sudbury in 1845, a little behind in 1855, and fairly in advance in 1865. The Shawshine is unrepresented in 1845, barely figures in 1855, and is about on a par with the Sudbury in 1865.

In Diagram VI. the Mystic has no representation. The cotton-works of the Charles appear in low figures throughout, with a slight advance in 1855 and decline in 1865. The Sudbury runs a parallel and inferior course in 1845 and 1855 and disappears in 1865. In Diagram VII. the products of Class III. are seen to be confined almost entirely to the Mystic, which in 1855 and 1865 is represented by considerable values. Minute values give a place to the Charles throughout, to the Shawshine in 1845, and to the Sudbury in 1865. In Diagram VIII. appear the values of products of industries of a miscellaneous character, called Class IV., and represent-

ing the total remainder. Here the Sudbury is seen to be third in valuation in 1845, second in 1855, and to take the lead in 1865, and by a large absolute valuation in proportion to its industries of other classes. The Mystic, leading all others in 1845 and 1855, is slightly behind the Sudbury in 1865. The Charles, second in value in 1845, is third in 1855 and 1865, although its figures are large as compared with those of its other industries. The Shawshine is represented by low figures throughout, with a gain in 1855 and a decline in 1865. Diagram IX. brings Classes I., II., and III. together into one large class.

We have examined the detailed information as to number and kind of manufactures in the several drainage areas, obtained in 1874 (see Appendix A), and on this basis have no difficulty in deciding that the Shawshine is first and the Mystic last in order of preference. Between the Sudbury and the Charles the comparison is closer and more difficult. To-day, the Charles, with twice the drainage area of the Sudbury, has rather more than twice as many tanneries, woollen, shoddy, felting, paper, cotton and saw-mills, while the Sudbury has more than half as many as the Charles of boot and shoe factories, print works (not yet started), grist-mills, and miscellaneous works, such as paint, dye, bonnet-frame, straw, leather-board, emery, plaster, cement, rope, brush, comb, carriage, cabinet, box and last establishments.

Comparing the whole number of establishments without regard to kind, the Sudbury has considerably more than the Charles. Comparing the number of works of the more objectionable sort, the majority of which are situated on the rivers and their tributaries (see Part Second, Description of rivers; also, Appendix A), the Charles has somewhat more than the Sudbury.

These results correspond to the showing of the diagrams. Referring again to these, it is seen that Classes I., II., and III. are represented by low figures for the Sudbury (Dia-

grams V., VII. and IX.), and by still low but higher figures for the Charles (Diagrams V., VI., VII. and IX.), while the comparison of totals without classification shows high figures for both the Sudbury and the Charles, with, generally, considerable difference between them.

The order of preference, therefore, based on the comparative risk of pollution by manufacturing refuse at the present day, will be

SHAWSHINE,
SUDBURY,
CHARLES,
MYSTIC.

Inasmuch, however, as the total industries of the Sudbury are greater in ratio per square mile than those of the Charles, and as the rate of growth of manufactures, so far as may be judged from comparable returns, has been more rapid in the former than the latter, we are led to give the following order of preference, as indicating the probable future risk of contamination by manufacturing refuse : —

SHAWSHINE,
CHARLES,
SUDBURY,
MYSTIC.

DENSITY OF POPULATION.

The density of population in the valley of a river cannot be determined with precision, since the dividing lines of townships, which form the basis of the census returns, do not coincide with those of the drainage areas. The following table gives the result of an approximate estimate of the population of the four river valleys, based in part upon the number of houses given on the county maps, and prepared at our request at the Engineer's office of the Boston Water Works : —

Population of Drainage Areas.

	Whole Drainage Area.	Per square mile.
Sudbury	16,722	229
Charles	25,149	165
Mystic	16,935	610
Shawshine	2,691	79

From this table it will be seen that, in regard to density of population and consequent danger of pollution of the waters by sewage and refuse, the rivers are to be preferred in the following order:—

SHAWSHINE,
CHARLES,
SUDBURY,
MYSTIC.

The above statement rests upon the assumption that the distribution of the population is similar in all the four drainage areas. This is approximately the case. The population is partly collected in towns, which are none of them large, Milford alone having a population of over 10,000 inhabitants, and partly scattered over the country and engaged in agricultural pursuits.

There is only one town, viz., Milford, in all the four river valleys which has pipe-drainage. The sewage of this town, which naturally drains into the Charles, can, as already mentioned, be diverted into the Blackstone; and should the Charles river be adopted as the source of supply for the city, it will of course be of the greatest importance that this diversion should be effected.

The danger of pollution of the rivers of which density of population gives the measure will therefore be chiefly that arising from indirect sewage, surface washings, and such

contaminating substances as cannot be excluded by legislation. The effect of this sort of contamination has been discussed in a previous portion of this report.

Not only the present, but the probable future, density of population in the different drainage areas is an important point to be considered in determining the comparative desirability of the four rivers in question. The future rate of increase may be determined with some degree of probability from the past, and the past rate may be estimated from a comparison of the population, as given by the decennial census returns of the towns lying wholly or in part in the different drainage areas. These statistics do not of course show the absolute population of the drainage areas at any given period, but a comparison of this sort will show the rate of increase in population of the towns lying in those sections of the State where the drainage areas are situated; and this is as near an approximation to the desired result as can well be made. The formation of new townships from portions of other townships lying, some within and others without a given drainage area, has introduced some slight inaccuracies into these estimates; but they are not considered to be of sufficient importance to affect the general result.

The following tables give the total population of the towns lying wholly or in part in the different drainage areas, every ten years, from 1800 to 1870, inclusive. The figures are taken from the State census returns, with the exception of those for 1870, which are copied from the United States census.

Population of the towns, wholly or in part in the drainage area of the

SUDBURY RIVER.

	1800.	1810.	1820.	1830.	1840.	1850.	1860.	1870.
Westboro'	922	1,048	1,326	1,438	1,658	2,371	2,913	3,601
Southboro'	871	926	1,030	1,080	1,145	1,347	1,854	2,136
Hopkinton	1,372	1,345	1,655	1,809	2,245	2,801	4,340	4,421
Marlboro'	1,735	1,674	1,952	2,077	2,101	2,941	5,907	8,475
Ashland }	Set off in 1846 from Framingham, Hopkinton and Holliston.					1,304	1,554	2,186
Framingham	1,625	1,670	2,037	2,313	3,030	4,252	4,227	4,969
Totals	6,525	6,663	8,000	8,717	10,179	15,016	20,795	25,788

Population of the towns wholly or in part in the drainage area of the

CHARLES RIVER.

	1800.	1810.	1820.	1830.	1840.	1850.	1860.	1870.
Hopkinton	1,372	1,345	1,655	1,809	2,245	2,801	4,340	4,421
Milford	907	973	1,160	1,360	1,773	4,819	9,132	9,890
Holliston	783	989	1,042	1,304	1,782	2,428	3,339	3,074
Bellingham	704	766	1,034	1,102	1,055	1,281	1,313	1,282
Franklin	1,285	1,398	1,630	1,662	1,717	1,818	2,172	2,513
Medway	1,050	1,213	1,523	1,756	2,043	2,778	3,195	3,721
Sherborn	775	770	811	899	995	1,043	1,129	1,049
Medfield	745	786	892	817	883	966	1,082	1,142
Dover	511	548	548	497	520	631	679	645
Natick	694	766	849	890	1,285	2,744	5,487	6,404
Wrentham	2,061	2,478	2,801	2,698	2,915	3,037	3,460	2,292
Norfolk }	Set off, in 1870, from Franklin, Walpole, Medway and Wrentham.							1,081
Totals	10,887	12,032	13,945	14,794	17,213	24,346	35,323	37,514

Population of the towns wholly or in part in the drainage area of the

MYSTIC RIVER.

	1800.	1810.	1820.	1830.	1840.	1850.	1860.	1870.
Winchester }	Set off in 1850 from Woburn, Arlington, and Medford.					1,353	1,937	2,646
Woburn	1,228	1,219	1,519	1,977	2,993	3,956	6,287	8,563
Stoneham	380	467	615	732	1,017	2,085	3,206	4,513
Burlington	534	471	508	446	510	545	606	626
Wilmington	797	716	786	731	859	874	919	866
Arlington	(?) 723	971	1,064	1,230	1,363	2,202	2,681	3,261
Lexington	1,006	1,052	1,200	1,543	1,642	1,893	2,328	2,277
Reading	Too small a part to be considered.							
Totals	4,668	4,896	5,692	6,659	8,334	12,908	17,964	22,752

Population of the towns wholly or in part in the drainage area of the

SHAWSHINE RIVER.

	1800.	1810.	1820.	1830.	1840.	1850.	1860.	1870.
Billerica	1,383	1,289	1,380	1,374	1,632	1,646	1,776	1,833
Bedford	538	592	648	685	929	975	843	849
Concord	Too small a part to be considered.							
Lincoln	766	713	706	709	686	719	717	791
Lexington	1,006	1,052	1,200	1,543	1,642	1,893	2,328	2,277
Burlington	534	471	508	446	510	545	606	626
Wilmington	797	716	786	731	859	874	919	866
Totals	5,014	4,833	5,228	5,488	6,258	6,652	7,189	7,212

For purposes of comparison, the total population of the towns lying wholly or in part in the different drainage areas are brought together in the following table : —

Total population in all the towns wholly or in part in the different drainage areas.

	1800.	1810.	1820.	1830.	1840.	1850.	1860.	1870.
Sudbury	6,525	6,663	8,000	8,717	10,179	15,016	20,795	25,788
Charles	10,887	12,032	13,945	14,794	17,213	24,346	35,328	37,514
Mystic	4,668	4,896	5,692	6,659	8,384	12,908	17,964	22,752
Shawshine	5,014	4,833	5,228	5,488	6,258	6,652	7,189	7,242

To facilitate comparison, the curves shown on Pl. X. have been constructed from the figures in the above table.

An examination of these curves shows that the population in and near the valley of the Shawshine river has remained comparatively stationary since 1800, while that in and near the other three valleys increased slowly till 1840, and since that time with much greater rapidity. The greatest absolute increase in population, as represented in these curves, was in the valley of the Charles, between 1850 and 1860 ; but this decade of rapid growth was followed by one in which the increase was much slower. In the valleys of the Sudbury and Mystic rivers the population has increased at a somewhat similar rate, and, as the total population represented is not very different in the case of these two rivers, the two curves are nearly parallel to each other.

In order to compare still more accurately the rate of growth of population in the different drainage areas, the following table has been calculated, giving the percentage growth of the towns in the four valleys for each decade from 1800 to 1870, and also the percentage growth for the whole of this period.

Percentage Growth of Towns in Drainage Areas.

	1800-10.	1810-20.	1820-30.	1830-40.	1840-50.	1850-60.	1860-70.	1800-70.
Sudbury	2.11	20.06	7.45	16.70	47.50	38.40	24.00	295.06
Charles	10.51	15.90	6.08	16.35	41.44	45.11	6.18	244.58
Mystic	4.88	16.26	16.99	25.90	53.96	39.17	26.65	337.41
Shawshine	-3.61	7.96	4.97	14.03	6.29	8.07	0.73	44.43

An examination of this table, or of the curves constructed from it (see Pl. XI.), shows that the growth of towns in and near the valley of the Shawshine has been uniformly less rapid than in the other three valleys.

The increase of population in and near the valley of the Charles has, in general, been less rapid than in that of the Sudbury, and in that of the Sudbury less rapid than in that of the Mystic. The most important exception to the above statement is in the case of the Charles river between 1850 and 1860. Here the growth was more rapid than in any of the other river valleys at the same period, but this rapid increase was offset by a remarkably slow growth in the following decade.

If we regard, therefore, growth of population in the past as an indication of the future probable rate of increase, the four rivers are to be preferred in the following order as sources of water supply :—

SHAWSHINE,
CHARLES,
SUDBURY,
MYSTIC.

This, it will be seen, is the same order in which the rivers stand when considered with reference to absolute density of population in their respective valleys at the present time.

In this connection it is important to call attention to a sub-

ject which will doubtless have a bearing upon the growth of population in the immediate neighborhood of the streams, viz.: the relation of the railroads to the rivers. In this respect the Sudbury is less favorably situated than any of the others, for the Boston & Albany R.R. runs close along its banks for a distance of nine miles, *i. e.*, from just above South Framingham to Westboro'. In the case of the Mystic river, the Boston, Lowell & Nashua R.R. runs for five or six miles close to its banks, and those of the Abajonna, its principal tributary. In the valley of the Charles, the only points where the railroads run close to the streams, are just below Milford, where the Milford Branch R. R. runs along the bank of the river for a distance of about two miles, and between Medway and Bellingham, where the Western Division of the N. Y. & N. E. R. R. is close to the river for about the same distance. In the valley of the Shawshine the railroads nowhere run in close proximity to the streams for any considerable distance.

It cannot, of course, be predicted with certainty that a dense population will spring up along a river bank wherever a railroad runs in its immediate neighborhood, for this may be prevented by a variety of local causes; yet, in consideration of the recognized influence of railroads on the growth of towns and villages along their lines, the indication thus afforded by their location of the future probable distribution of the population should not be altogether disregarded.

CHEMICAL COMPOSITION.

In considering the analyses of the Charles, Sudbury and Shawshine rivers, it must be remembered that the waters had not had the benefit to be derived from storage in large reservoirs, and consequently that the water, as delivered to consumers in the City, will be much better in quality than that found in the river beds. If no storage basins were proposed, none of these river-waters could be recommended for

domestic use, except, possibly, the Shawshine, and even this could not be expected to have at all seasons, and under all circumstances, the same degree of purity as during the season of drouth just passed, when there were no surface runs, and the water was, consequently, almost purely a spring water.

We have been unable, on account of the limited time allowed us, to collect and examine more than one specimen from each of the different points on the various rivers selected as the most suitable ones for collection; and since it is important in forming an opinion upon the average composition of a running water, that as large a number of analyses as possible should be made of specimens collected at different seasons, we have compared our results with those of Prof. W. R. Nichols, of the Mass. Institute of Technology, as published in the last report of the Mass. State Board of Health, and in City Doc. No. 38, Appendix II. We have compared with our own, only those analyses of Prof. Nichols which were of waters falling within the limits of our investigations.

Prof. Nichols' analyses of the Sudbury river may be found on page 104; of the Charles (between South Natick and Newton Upper Falls), on page 98; of the Mystic, on page 142; and of Lake Cochituate, on page 125 of City Doc. No. 38.

It will be seen that the water of the Shawshine, that of those head-waters of the Charles and the Sudbury, on which there are no sources of pollution, and that of the Abajonna above the Chemical Works, do not differ materially from each other in chemical composition, nor from the average Lake Cochituate water, as shown by Prof. Nichols' analyses, excluding those of Pegan brook.

The average composition of the water of the Charles and Sudbury rivers, taking into consideration the analyses of the worst as well as the best samples, is much better than that of

Mystic-lake water collected at the gate-house and Bacon's bridge, although the river-waters have not received the benefit of storage.

By a careful comparison of all of the analyses at our disposal of the water of the various streams, we would arrange them according to their chemical composition, in the order of relative desirability, as follows :—

SHAWSHINE,
SUDBURY,
CHARLES,
MILL BROOK,
MYSTIC.

The following is a statement of the number of analyses from which our deductions have been drawn :—

Charles river	(Wood)	.	17	
“ “	(Nichols)	.	18	
“ “ Total	.	.	.	35
Sudbury river	(Wood)	.	9	
“ “	(Nichols)	.	14	
“ “ Total	.	.	.	23
Shawshine river	(Wood)	.		3
Mill brook	(“)	.		3
Mystic river	(“)	.	6	
“ “	(Nichols)	.	10	
“ “ Total	.	.	.	16
Lake Cochituate	(Nichols)	.		17
Total number of analyses	.	.	.	97

OPPORTUNITIES FOR STORAGE.

To determine in which of the four schemes the best storage facilities are provided, we must consider

I. *The contents of the storage basins in proportion to the*

drainage area. — Upon this will depend, other things being equal, the length of time during which the water will remain stored and consequently the opportunity it will have for self-purification.

II. *The proportion of shallow flowage to the total contents of the basins.* — This will give a measure of contamination of the water likely to be produced by the growth and decay of vegetable matter in those parts of the basins where the depth is insufficient to prevent such growth.

III. *The number and arrangement of the basins.* — Upon this will depend the possibility of holding back a portion of the water-supply which may have become impure from local causes, and giving it the benefit of prolonged storage.¹

In regard to the first of these three questions, approximate estimates, made at our request in the Engineer's office, have shown that the Sudbury, Charles and Mystic river schemes do not differ greatly from each other, while in the valley of the Shawshine nearly 50 % more storage is provided for each square mile of drainage area than in any other river valley. In this respect, therefore, the Shawshine-river scheme possesses a decided advantage over the others.

To enable us to decide upon the relative merits of the four schemes considered with reference to the second of the points above enumerated, or, in other words to determine in which scheme for water-supply the water will be least likely to be contaminated with the products of vegetable decomposition resulting from shallow flowage, the following approximate estimates have been furnished us by Mr. Fteley.

¹ For instances where the water of lakes and ponds has been thus rendered impure, see report of the Cochituate Water Board to the City Council of Boston, for the year 1854.

	No. of gals. of storage per acre of shallow flowage (i. e., less than 5 ft. deep).
Sudbury	27,000, 00
Charles	31,000,000
Mystic	7,600,000
Shawshine	30,000,000

From this table it will be seen that the impurities arising from the decomposition of the vegetable matter on each acre of shallow flowage will be distributed, in the case of the Mystic river, through 7,600,000 gallons of water, and in the case of the other three rivers through amounts varying from 27 to 31 millions of gallons. In other words the waters of the Charles, Sudbury and Shawshine river basins will not differ materially from each other in respect to the amount of vegetable contamination derived from shallow flowage, while the water of the Mystic-river basins may be expected to contain about four times as much of this sort of impurity as that of the other rivers. Taking the figures of the above table as a guide, the four rivers in question are, in respect to this sort of contamination, to be preferred in the following order: —

CHARLES,
SHAWSHINE,
SUDBURY,
MYSTIC.

It should be mentioned here that the reason why the Sudbury river appears in this list as somewhat inferior to the Charles and Shawshine rivers is, that Whitehall pond, with its large extent of shallow flowage, is included among the storage basins of this valley. It must be borne in mind, however, that the water of this pond will flow twelve miles along the bed of the river, and pass through Basins II. and I.

and Farm pond before reaching the conduit, and will thus have an excellent opportunity for self-purification.

From what has been said, in the second part of this report, of the number and arrangement of the proposed storage basins in the different drainage areas, it is evident that the four schemes differ greatly from each other in the facilities which they offer for giving the benefit of prolonged storage to water which has become impure from local or temporary causes. A careful examination of the plans of all the proposed storage basins (as given in the Engineer's reports), with a view of determining the relative merits of the four schemes in this respect, has led us to the opinion that the rivers are to be preferred in the following order : —

SUDBURY,
MYSTIC,
SHAWSHINE,
CHARLES.

It will thus be seen that our estimate of the relative merits of the storage facilities offered by the different schemes will vary greatly, according as we consider the storage basins with reference to the opportunities offered for the self-purification of water, or with regard to the probable contamination of the water by the decomposition of vegetation growing in the shallow portions, or in respect to the facilities provided for giving the benefit of prolonged storage to a portion of the water-supply, which, from local causes, may have become unfit for use. Although, as above stated, the size of the proposed storage basins relatively to the drainage area is much greater in the valley of the Shawshine than in that of the other rivers, yet it is probable that the storage basins provided in *all* the schemes are sufficiently extensive to allow ample time for the self-purification of the water. If, therefore, we leave this consideration out of sight, the question is much simplified.

The Mystic-river scheme is, as we have seen, decidedly inferior to the other three in respect to the amount of shallow flowage in the proposed storage basins, while these three, though essentially alike in this respect, differ greatly from each other in the facilities which they offer for the prolonged storage of portions of the water-supply.

With regard, therefore, to the general question of storage facilities, the four schemes are to be preferred in the following order : —

SUDBURY,
SHAWSHINE,
CHARLES,
MYSTIC.

CONCLUSION.

The four sources of supply, as hereinafter enumerated, are placed in the order of preference (the best being first, and so on) as to the respective matters under which they are arranged.

1. Character of the water.

(a) Color, taste and general appearance.

1. SHAWSHINE.
2. CHARLES.
3. SUDBURY.
4. MYSTIC.

(b) Chemical analysis.

1. SHAWSHINE.
2. SUDBURY.
3. CHARLES.
4. MYSTIC.

2. Opportunities for storage.

1. SUDBURY.
2. SHAWSHINE.
3. CHARLES.
4. MYSTIC.

3. Sources of pollution.

(a) Population, present.

1. SHAWSHINE.
2. CHARLES.
3. SUDBURY.
4. MYSTIC.

(b) Population, future.

1. SHAWSHINE.
2. CHARLES.
3. SUDBURY.
4. MYSTIC.

(c) Manufacturing refuse, present.

1. SHAWSHINE.
2. SUDBURY.
3. CHARLES.
4. MYSTIC.

(d) Manufacturing refuse, future.

1. SHAWSHINE.
2. CHARLES.
3. SUDBURY.
4. MYSTIC.

The Mystic being in all these respects the last in order, and therefore the least desirable, we may pass to the consideration of the three remaining rivers. Of these, the Shawshine is best in every respect excepting opportunities for storage, in which it is surpassed by the Sudbury alone. It remains to compare the Sudbury and the Charles. The Sudbury is preferable to the Charles in the results of chemical analysis, in opportunities for storage, and in present risk of contamination by manufacturing refuse. The Charles is superior to the Sudbury in the color, taste and general appearance of the water, and in risk of contamination by present and future population, and by future manufacturing refuse. The probability is, therefore, that chemical analysis will turn ultimately

in favor of the Charles, leaving to the Sudbury of the future the sole advantage of superior storage facilities.

The resultant estimate, therefore, of the sanitary qualities of the four rivers places them in the following order of preference : —

1. SHAWSHINE.
2. CHARLES.
3. SUDBURY.
4. MYSTIC.

It will be asked, —

I. How do the differences between each two successive rivers in the above list compare with each other?

II. To what extent is this order determined by conditions which may be affected by legislative enactment?

III. Should no financial considerations be allowed to affect the estimate thus formed?

In reply it may be said : —

1. The Mystic river, even without reference to the direct sources of pollution, is, on account of the dense population in its valley and the inferior storage facilities, *much less* desirable than the other rivers as a source of water-supply.

Between the other three rivers the difference is less marked, though the Shawshine is, for reasons enumerated above, distinctly superior to the Charles and Sudbury. Though the two latter rivers differ at present less from each other than from either the Shawshine or the Mystic, this difference will be probably much more marked in the future.

2. That the natural, *uncontaminated* waters of all of the rivers under consideration may, by proper storage, be made sufficiently pure for domestic use ; but in order to render them uncontaminated, and to ensure their future purity, *all* existing sources of pollution must be removed.

3. That, in order to remove all existing sources of pollu-

tion, and to prevent others from being established in the future, suitable legislative enactment must be obtained.

4. That the inability to procure such legislative enactment in regard to either river would be sufficient reason for rejecting that river as a source of water-supply.

5. That, as the sanitary question is paramount to all other considerations, no scheme involving imperfect storage facilities or insufficient legislative protection of the waters should be adopted from motives of economy.

It must be remembered, however, that, even with the most favorable legislative act and the most perfect engineering schemes, it will be impossible to prevent a certain amount of pollution from entering a river flowing through a thickly settled district.

SUPPLEMENT.

Subsequent to our appointment to consider and report upon the sanitary qualities of the Sudbury, Charles, Mystic and Shawshine waters, the question involved in the following order was referred to us by the Joint Standing Committee on Water : —

“Ordered, That the Joint Standing Committee on Water consider and report upon the necessity and expediency of using Lake Cochituate as an intermediate storage basin for the diffusion and purification of the Sudbury-river water, if said river is adopted for an additional supply.”

Unfortunately, the wording of this order does not render it clear whether we are to consider and report upon the use of Lake Cochituate as a storage reservoir for the Sudbury-river water without its having received previous storage, or after it has been previously stored in basins according to the plans proposed in the Sudbury-river scheme.¹

¹ City Doc. No. 38.

It is needless to add anything to what has already been said in the foregoing report upon the effect of storage in general upon water. There can be no doubt that the effect of storing in Lake Cochituate the Sudbury-river water, as it runs in the river bed at present, would be very beneficial; but if the lake is to be the only storage reservoir for its purification, it would, in our opinion, be overtaxed, and the benefit which would result from such storage would be more than counterbalanced by the injury which would be done to the lake water by admixture with the highly colored and more impure water of the Sudbury river; since, if so large an amount is allowed to flow through the lake as will be necessary several years hence, its passage will necessarily be too rapid to permit of its thorough purification, and it will probably be delivered to consumers in the city quite highly colored from admixture with the Sudbury river and Beaver Dam brook water, both of which are very deeply tinged.

The amount of injury, however, which would be done to the water of the lake, as well as the beneficial effect upon that of the river, would depend very much upon the selection of the point at which the connection between the river and the lake would be made. If the Sudbury river is to be connected with the Beaver Dam brook, as in 1872, and its water consequently introduced into the southern division of the lake, not only would the benefit to the one be greater, but the injury to the other would be much less, than if introduced into the northern division near the gate-house.

After the connection between Farm pond and Lake Cochituate was made in 1872, it will be remembered, the water of the latter was very turbid and impure. No argument can be drawn from this, however, against such connection, since it is by no means certain how much of this impurity was due to the Sudbury-river water, and how much to the previous exposure to the air of two hundred

acres or more of the lake bottom, which is usually covered with from five to seven feet of water.

This plan, therefore, cannot be as highly recommended as the excellent system of storage basins which have been proposed upon the Sudbury river itself.

Concerning the value of Lake Cochituate as an additional storage reservoir to those already proposed upon the river itself, we can only state, that the greater the amount of storage which a water receives the better. It is quite probable, however, that the water of Sudbury river, in Basin No. I., or in Farm pond, will be quite as good as that of Lake Cochituate itself; and it is also probable, that the benefit to be derived from the additional storage in the lake would be counterbalanced by the impurities which it would receive in flowing through the ditch from Farm pond to Beaver Dam brook, and through the bed of the latter to the lake.

In our opinion, therefore, if storage basins are to be erected upon the Sudbury river itself, as in the proposed plan, the use of Lake Cochituate as an additional storage reservoir is not necessary. If, on the other hand, it is proposed not to erect any storage basins upon the river itself, the use of Lake Cochituate as an intermediate storage reservoir for the purification of the Sudbury-river water, is not expedient (except temporarily in times of necessity), owing to the injurious effect which would be exerted upon the water of the lake.

In connection with this subject, it may be well to consider two very obvious sources of pollution in Lake Cochituate, the removal of both of which would render its water more suitable for domestic use. One of these, Pegan brook, which empties into the lake, receives a portion of the drainage of Natick, numerous sink-drains and privies discharging their contents directly into the brook. This should be diverted, as has already been proposed.¹ The other is the

¹ See order passed in Common Council, Oct. 22, 1874.

large extent of shallow flowage in the southern division, which, in seasons of drouth like that just passed, is exposed to the atmosphere to the extent of two hundred acres or more. This gives rise to a large amount of vegetable growth, which, in decaying, imparts to the water a correspondingly large quantity of decomposing vegetable matter, the effect of which has been spoken of in the preceding report. The prevention of this, by dredging or otherwise, would necessarily, at such seasons, have a very beneficial effect upon the water of the lake.

CHAS. W. SWAN, M.D.

EDW. S. WOOD, M.D.

H. P. BOWDITCH, M.D.

APPENDIX A.

REPORT OF MR. D. W. CUNNINGHAM ON POPULATION AND MANUFACTURES.

OFFICE OF BOSTON WATER WORKS, }
ADDITIONAL SUPPLY, }
SOUTH FRAMINGHAM, Oct. 9th, 1874.

MESSRS. CHARLES W. SWAN, M. D., EDWARD S. WOOD,
M. D., HENRY P. BOWDITCH, M. D. : —

Gentlemen, — Herewith I forward a list of all the manufacturing establishments within the drainage areas of the several water-sources, and the population of each per square mile.

Respectfully submitted,

(Signed,)

DAVID W. CUNNINGHAM,
Prin. Asst. Eng'r New Supply.

Charles River.

MILLS ON THE STREAM, ABOVE DEDHAM, AND USING WATER POWER.

	Towns.	Employés.
Two grist-mills	Milford and So. Natick.	5
One woollen-mill (burnt down)	South Milford.	120
One saw and grist-mill	Bellingham.	3
Two shoddy-cloth factories	North Bellingham.	125
One shoddy factory	Bellingham.	6
One woollen flock's mill	North Medway.	4
One thread factory, two batting-mills	Medway.	40
Three coarse paper factories	Rockville and Needham.	20
One saw-mill, batting and bonnet frames	Medway.	12
One leather-board manufactory	South Natick.	12
Total, 15 factories; employing		347

TRIBUTARIES TO CHARLES RIVER.

1st Tributary.	<i>Beaver pond outlet</i> (left bank).		0
2d "	<i>Stall brook</i> (left bank).		
	One saw-mill		2
3d "	<i>Hopping brook</i> (left bank).		
	Two saw-mills		9
4th "	<i>Mine brook</i> (right bank).		
	Three saw-mills	Franklin.	16
	One felting-mill	"	28
	Two shoddy-mills	"	35
	One machine-shop	"	10
5th "	<i>Chicken brook</i> (left bank).		
	One machine-shop	West Medway.	3
	Two saw-mills	"	10
6th "	<i>Shepherd's brook</i> (right bank).		
	One saw-mill	Franklin.	2
	One shoddy-mill	"	4
	<i>Carried forward</i>		400

TRIBUTARIES TO CHARLES RIVER. — *Continued.*

Tributary.		Towns.	Employés.
	<i>Brought forward</i>		466
7th Tributary.	<i>Mill river</i> (right bank).		
	Two cotton-mills	Norfolk.	100
	One felting-mill	"	200
	One grist-mill	"	
	One shoddy-mill	"	
	One cabinet-shop	Franklin.	2
	One edge-tool factory	"	6
8th "	<i>Stop river</i> (right bank).		
	One wrapping-paper mill	Norfolk.	12
	Three saw-mills (two not in use) . .	"	1
	One shoddy-mill	"	3
	One grist-mill	Medfield.	1
9th "	<i>Medfield brook</i> (right bank).		
	Two carriage-factories	"	30
10th "	<i>Harding's brook</i> (right bank).		
	Two saw-mills	"	8
11th "	<i>Bogistow brook</i> (left bank).		
	One nail-factory	East Holliston.	15
	One machine-shop (not at work) . .	"	0
	Four saw-mills (one not in use) . .	Medway and Holliston.	15
	One saw and grist-mill	Holliston.	4
12th "	<i>Ware's brook</i> (left bank).		
	One wheelwright and blacksmith shop	Sherborn.	3
	One saw and grist-mill (not used) . .	"	0
13th "	<i>Savin's brook</i> (left bank).		
	One saw and one grist-mill	South Natick.	2
14th "	<i>Bacon's brook</i> (left bank).		
	Old grist mill (not used)	"	0
	<i>Carried forward</i>		863

CHARLES RIVER TRIBUTARIES. — *Concluded.*

Tributary.		Towns.	Employés.
	<i>Brought forward,</i>		868
15th Tributary.	<i>Waban brook</i> (left bank).		
	Wood's paint works	Natick.	10
	Woods' cement brick factory (burned)	"	0
	Jennings' saw-mill and shoe-knife factory	"	6
16th "	<i>Trout brook</i> (right bank).	Dover.	0
18th "	<i>Noanet's brook.</i>	"	
	One old saw and keg factory (not at work)	Dedham.	0
20th "	<i>Schlusemeyer's brook.</i>	"	
	One saw and planing-mill (not at work)	"	0
Total, 60 mills	Total number employed in mills that are run by water power, about		884

Charles River.

FACTORIES NOT USING WATER POWER.

MANUFACTURE.	Towns.	Employés.
Gas works	Milford.	
Two box-factories and saw-mills	"	
Paint-factory	"	
Machine-shop	"	
Milford dye-house	"	
Last-factory	"	
Boot-form factory	"	
Sixteen boot and shoe factories	"	
Two boot and shoe factories	Hopkinton.	
Fourteen shoe-factories	Holliston.	
One copper-pump works	"	6
One comb-factory	"	
One shoe-factory	Bellingham.	

*Charles River.*FACTORIES NOT USING WATER POWER— *Continued.*

MANUFACTURE.	Towns.	Employés.
<i>Brought forward</i>		6
Four straw-factories	Franklin.	
One boot-factory	"	6
One sash and blind factory	"	
One felting mill (steam)	"	20
One tannery	"	25
Nine shoe-factories	Medway.	
One bell-foundry	"	
One organ-factory	"	
Two vegetable-canning factories	"	100
Two shoe-factories	Sherborn.	
One piggery	"	
One cider-mill	"	
Two straw-factories	Medfield.	
One brush-factory	"	
One tannery	"	
One shoe factory	"	
Total		157

Sudbury River.

FACTORIES ON THE MAIN STREAM ABOVE FARM POND.

MANUFACTURE.	Towns.	Employés.
Two woollen-factories (horse blankets)	Southboro'.	125
One shoddy and batting-factory	Ashland.	3
Four saw-mills	Westboro' and Ashland.	8
Three grist and plaster-mills	Westboro' and Ashland.	16
Dwight printing company (not yet started)	Ashland.	5
Two emery-mills (only one using water-power)	"	19
<i>Stony brook (branch of Sudbury).</i>		
Two grist-mills	Southboro'.	4
One grist and plaster-mill	"	2
One saw and grist-mill	"	2
One old machine-shop (not in use)	"	0
<i>Whitehall brook.</i>		
One saw and grist-mill	Hopkinton.	1
One boot and shoe-factory	"	30
One twine-factory	"	0
<i>Cold Spring brook.</i>		
Two saw and grist-mills	Hopkinton.	5
<i>Angle brook.</i>		
Two old mill-sites (not in use)	Marlboro'.	0
Total		220

Sudbury River.

FACTORIES NOT USING WATER POWER.

MANUFACTURE.	Towns.	Employés.
Seventeen boot and shoe-factories	Marlboro'.	
One machine-shop (steam)	"	
One box-factory (steam)	"	
One cider-mill	"	
One gas-works (not yet started)	"	
Three boot and shoe-factories	Westboro'.	
Six straw-factories	"	
Four sleigh-factories	"	
One planing-mill and box-factory	"	
One brick-yard	"	
Four boot and shoe-factories	Hopkinton.	
One steam box-factory	"	
Eight boot and shoe-factories	Ashland.	
Two boot and shoe-factories	Southboro'.	
One brickyard	"	

Shawshine River.

	Towns.	Employés.
<i>Factories upon the Stream.</i>		
William Ashby's saw and grist-mill and cider-mill . .	Bedford.	3
<i>Vine brook.</i>		
One saw and planing-mill	"	1
One saw, grist and cider-mill	Burlington.	2
One block-printing establishment	"	16
Total		22

Mystic Pond.

MANUFACTURE.	Towns.	No. of Hides per week.	Employés.
<i>Factories on the Abajonna river above Mystic pond.</i>			
Four tanneries and curry-shop	Winchester & Woburn.	1,400	173
One glue-stock factory	E. Woburn.		50
One glue-factory (about starting)	"		
One watch-hand factory	"		10
One saw and grist-mill	N. Woburn.		4
One saw-factory	E. Woburn.		12
One rope-walk	"		7
One saw and planing-mill	Winchester.		10
<i>Factories on the West or Horn pond branch.</i>			
Woburn gas-works			
Sixteen tannerles and currier's shops . .	Winchester & Woburn.	6,775	1,103
Two tanneries and currier's shops	Cummingsville.	1,600	265
One wool-scouring establishment; scours 4,000 lbs. wool per day, from which 2,000 lbs. of grease or dirt are thrown into stream. }	Winchester.		15
One mahogany saw-mill	"		8
One glue-factory	Cummingsville.		
<i>Stoneham branch.</i>			
Four tanneries and curriers' shops		1,550	196
Fourteen shoe-factories			970
Two inner-sole and stiffening-factories . .			120
One saw and planing-mill			24
One last-factory			8
<i>Factories within the Mystic water-shed not on the stream.</i>			
Three currying-shops	Winchester.		70
One grain-mill (large)	Woburn.		
Five currying-shops	Woburn Centre.	2,400	142
Four " "	N. Woburn.	160	26
<i>Amount carried forward</i>			3,213

	Towns.	No. of Hides per week.	Employés.
<i>Amount brought forward</i> . . . . .	.....	.....	3,213
One stiffening and heel-factory	N. Woburn.		3
One rope-walk	E. Woburn.		6
One old privilege, formerly a grist-mill . .	"		0
Nine ladies' shoe-factories	Woburn.		150
Two " " "	N. Woburn.		100
Total 81 factories.			
Total number employed in 81 factories within the Mystic drainage area . . .	.....	.....	3,472

Population (approximate).

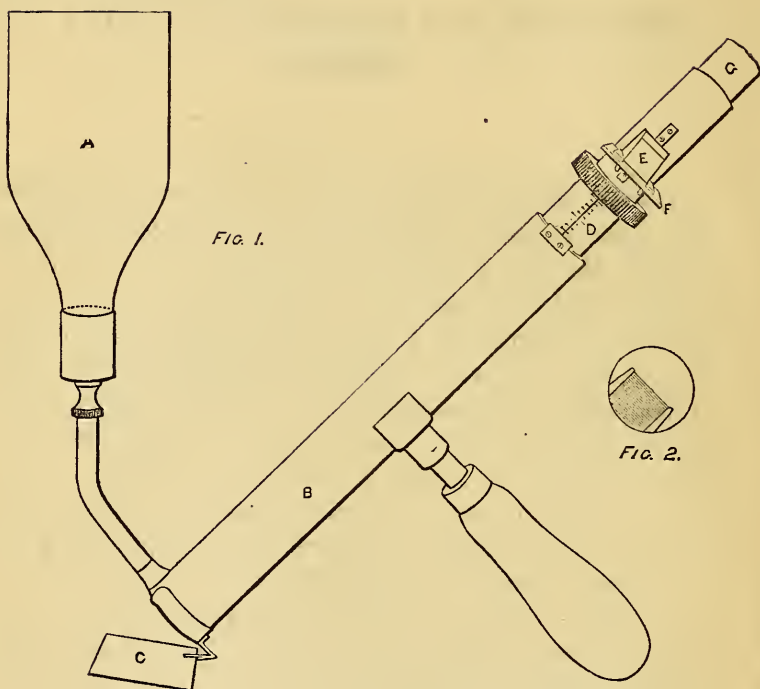
<i>Charles river</i> , above South Natick, whole drainage area	25,149
" " per square mile	165
<i>Sudbury river</i> , whole drainage area	16,722
" " per square mile	229
<i>Mystic pond</i> , drainage area	16,935
" " per square mile	610
<i>Upper and Lower Mystic ponds</i> , whole drainage area	20,625
" " " per square mile	618
<i>Shawshine river</i> , above old canal crossing, whole drainage area . .	2,691
" " per square mlle	79

APPENDIX B.

OBSERVATIONS AND EXPERIMENTS ON COLOR AND STORAGE.

It soon became evident in the course of our investigations that some method of estimating and comparing the depth of color of the various waters, more accurate than that afforded by the unaided vision, was a decided desideratum. Our attempts to supply this want resulted finally in the construction of an instrument of which the following woodcut gives a diagrammatic representation on a scale of about three and a half inches to the foot. The instrument consists of two tubes, B and D (Fig. 1), sliding water-tight, one within the other, the lower end of each tube being closed with a disc of plate glass. Into the large tube, B, just above the plate-glass disc, is inserted a piece of small tubing which terminates in a funnel-shaped receiver, A. Water poured into this receiver will therefore pass into the space between the two glass discs, entirely filling the outer tube when the inner tube is withdrawn, and again returning to the receiver when the inner tube is pushed down so that the glass discs come in contact with each other. Through an opening near the upper end of the smaller tube, D, is inserted one end of a rhombic prism, E, in which total internal reflection takes place twice.

This prism extends half-way across the inner tube, D, so that an eye, looking through the eye-piece, G, sees the field of vision nearly half filled by the surface of the prism. This appearance is represented in Fig. 2. The eye-piece, G, con-



tains a single lens, which is focused upon the upper surface of the prism. The position and angles of the prism are such that a ray of light outside of and parallel to the tube B is reflected first directly into the tube D, and then parallel to its axis, thus emerging from the prism and entering the eyepiece alongside of the rays of light which have passed through the two plate-glass discs. It will thus be seen that the conditions for comparing the color and intensity of these two sources of light are as favorable as possible. A piece of white card, C, fastened at the lower end of the larger tube, throws a uniform white light through the tubes B and D, and also along the outside of the tube B into the prism, E.

In using the instrument, a piece of brownish-yellow glass, F, is placed in front of the prism, E, and the water whose color is to be determined is poured into the receiver, A. The inner tube is then withdrawn until the column of water between the two glass discs is sufficiently long to give to the light passing through it a color equal to that imparted by the colored glass, F, to the light passing through the prism, E. The length of this column of water, which will of course vary inversely with the depth of the color, can be determined by means of the scale on the inner tube, D.

By this means the relative intensity of color of various specimens of water may be determined with considerable accuracy.

Color. — In order to determine if possible upon what constituent of river water its color depends, careful color determinations were made of a number of samples by means of the instrument above described. In the following table, giving the results of chemical analysis, these samples are arranged in the order of their color, beginning with the darkest, the figures in the column headed "color" giving the length in inches of the column of water capable of imparting to transmitted light a color equivalent to that of the brownish-yellow glass used as a standard.

Parts in 100,000.

	Color.	Ammonia.	"Albuminoid" Ammonia.	Inorganic.	Organic.	Total Residue.	Chlorine.
Sudbury river, above Ash- land }	2.42	0.002	0.031	4.2	1.8	6.0	0.8
Sudbury river, below Ash- land }	2.72	0.0034	0.036	4.8	3.4	8.2	1.2
Mine brook, near source . . .	3.37	0.0054	0.032	3.0	3.8	6.8	0.6
Winthrop pond, above Hol- liston }	3.69	0.008	0.023	2.6	3.0	5.6	1.0
Jar brook below Holliston .	3.85	0.010	0.042	2.6	3.0	5.6	1.75
Cedar Swamp pond, above Milford }	4.87	0.018	0.024	2.6	2.2	4.8	0.8

An examination of this table shows that the only constituent of the water which undergoes a progressive change corresponding to the color is the free ammonia. This gas is seen to increase in amount as the color diminishes, suggesting the possibility that the color may be due to a nitrogenous substance whose decomposition gives rise to ammonia. Whether this is really the case, or whether the apparent relation between color and amount of No. 3 is only a coincidence, is a question requiring for its solution more extensive investigations than the time at our disposal permitted us to undertake.

Storage. — The following experiments were made with the view of investigating the nature of the process by which the purification of water is effected in storage basins.

A quantity of water was collected from the Sudbury river, and a portion of it analyzed. Its color was also determined by means of the instrument above described. The water was then filled into three tall glass jars, which were tightly closed and then allowed to stand for fifteen days, the first in absolute darkness, the second in the diffused light of the laboratory, and

the third in a southern window, where it was exposed to the direct rays of the sun during the greater part of the day.

Another portion of the same water was placed in a large bottle with a stop-cock at the bottom, through which it was allowed to flow drop by drop from a height of ten feet into a receiver placed below. When all the water had passed through, it was again returned to the bottle, and the process repeated ten times. Enough distilled water was then added to make good the loss by evaporation during the experiment, and the color and chemical composition were determined. In this experiment the greatest possible opportunity was given for the action of the oxygen of the air, and all those changes in the water which depend upon the oxidation of organic substances would naturally be produced to their greatest extent.

In the three first-mentioned experiments, on the other hand, a determination of the color and chemical composition of the water gave us the means of estimating the effects of light of varied degrees of intensity in the absence of contact with the external air. It would be extremely hazardous to draw conclusions from a single set of experiments, which was all that the limited time at our disposal permitted us to make. It will be sufficient, therefore, to say that in all the experiments there was a diminution of color, and that in the three jars exposed to light of varied intensity the diminution increased with the intensity of the light.

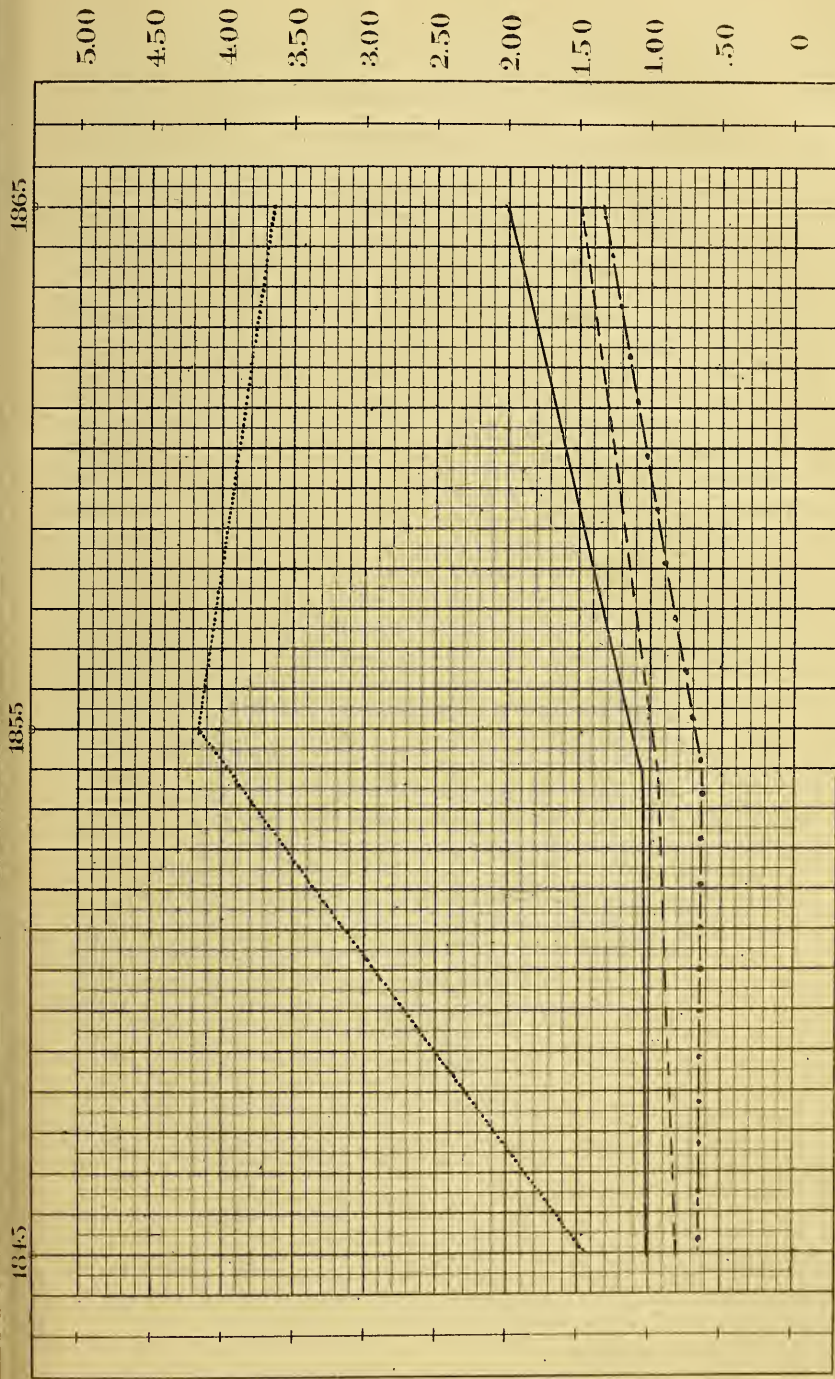
In the water exposed to oxidation by dropping slowly through the air no greater change of color was noted than in that which was exposed in a closed jar to the diffused light of the laboratory.

From the following table, giving the results of chemical analysis, it will be seen that there was a diminution of the solid constituents, both organic and inorganic, which in a general way corresponded to the diminution of color, while

the relation between ammonia and color was not so evident as in the observations previously described.

Parts in 100,000.

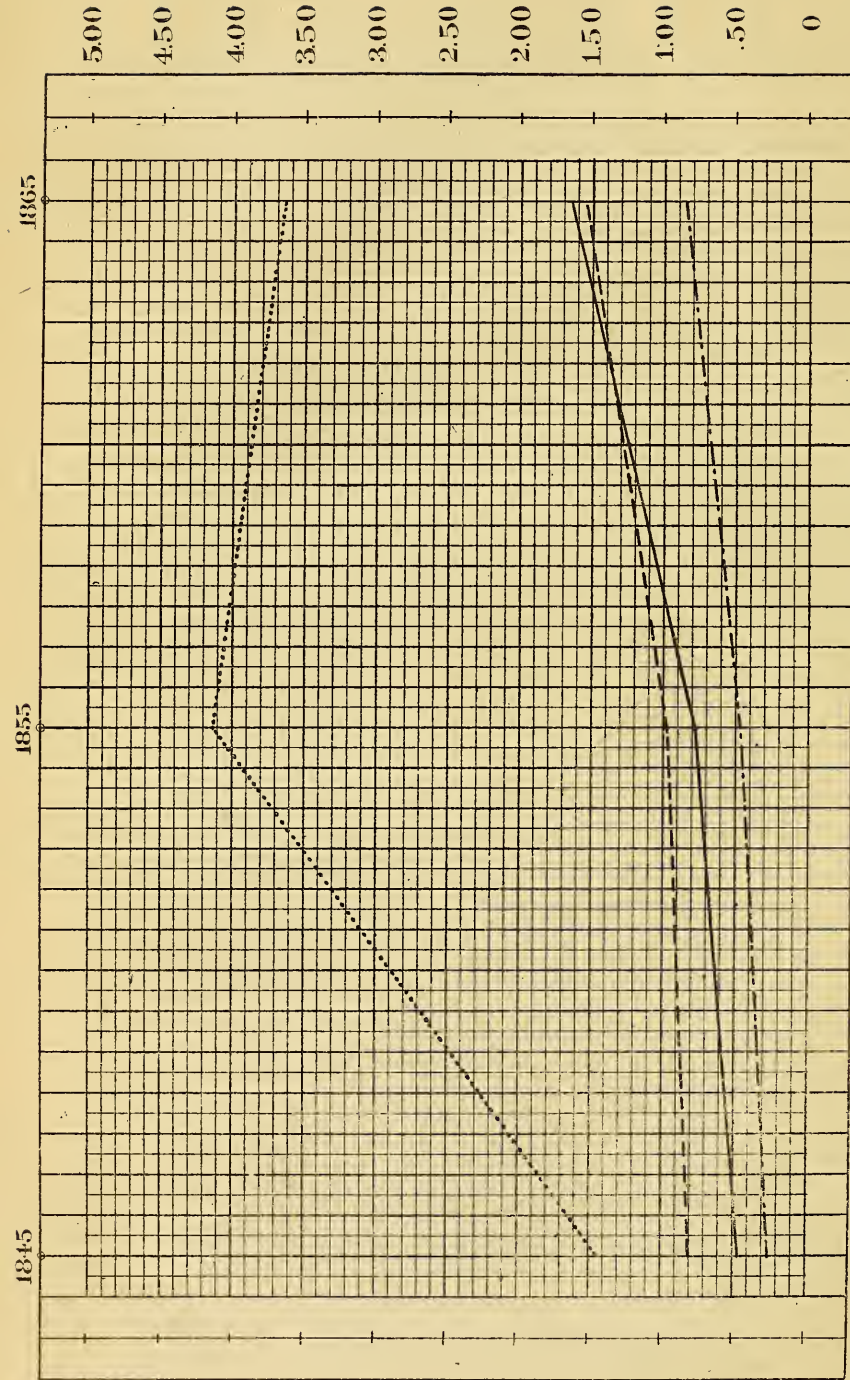
	Color.	Ammonia.	"Albuminoid," Ammonia.	Inorganic.	Organic.	Total Residue.	Chlorine.
Water when received	4.30	0.0016	0.029	3.6	3.8	7.4	0.8
After fifteen days in darkness	5.25	0.008	0.025	3.4	3.2	6.6	0.8
After fifteen days in diffused light }	5.82	0.005	. . . .	2.8	3.6	6.4	. . . .
After fifteen days in sunlight	6.20	0.0016	0.027	2.8	3.2	6.0	0.7
After passing ten times through bottle }	5.60	0.0132	0.0223	2.8	3.6	6.4	0.7



Ratio per square mile of number of manufacturing Establishments in each area
(including Framingham & Billerica)

Mystic..... Charles---- Sudbury— Slawshine....

II.

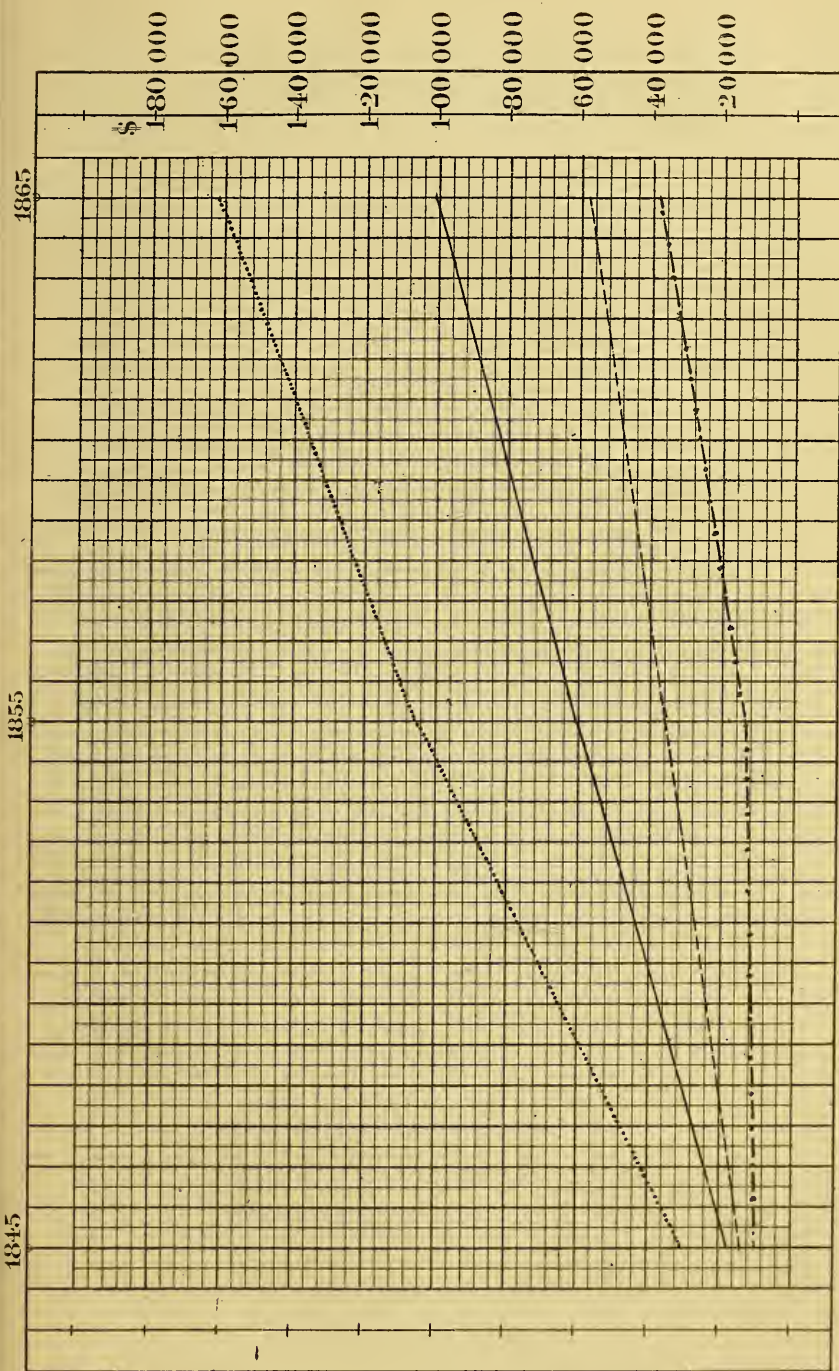


Ratio per square mile of number of manufacturing Establishments in each area.

(Omitting Frammingham & Billerica.)

Mystic..... Charles----Sudbury—— Shawshine-----

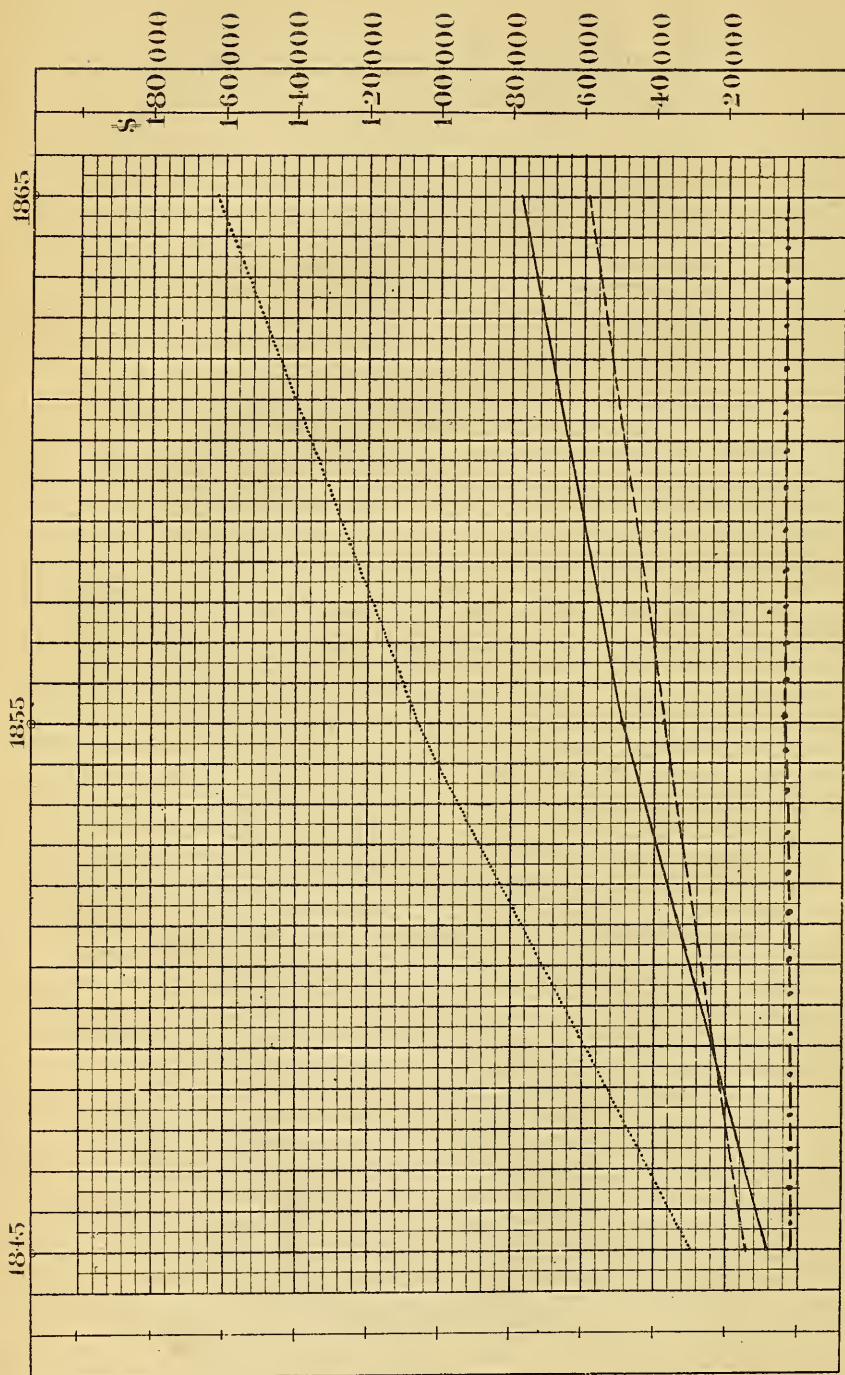
III.



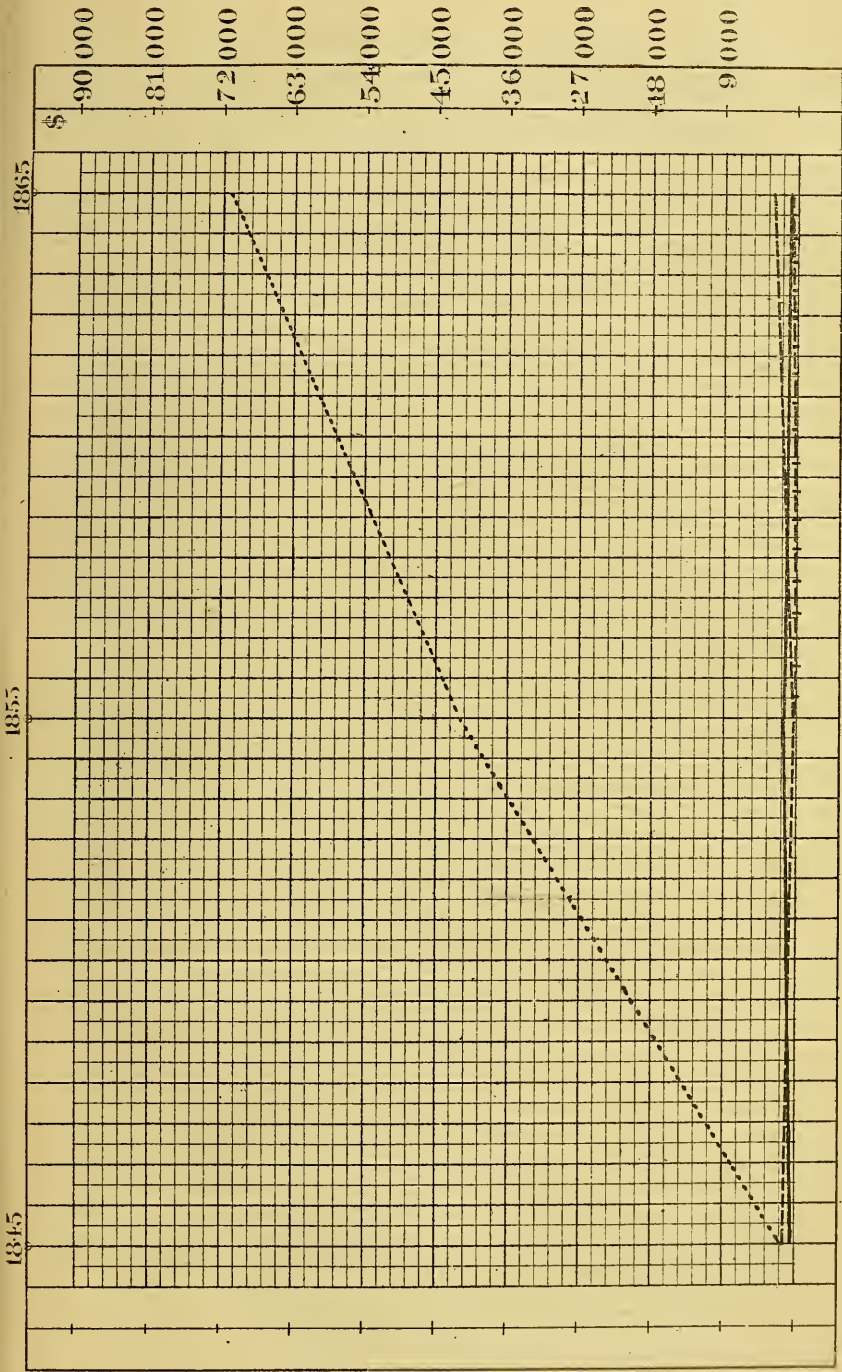
Ratio per square mile of total value of manufactured products of each area.
(Including Framingham & Billerica.)

Mystic..... Charles----Sudbury— Shawshine----

IV.



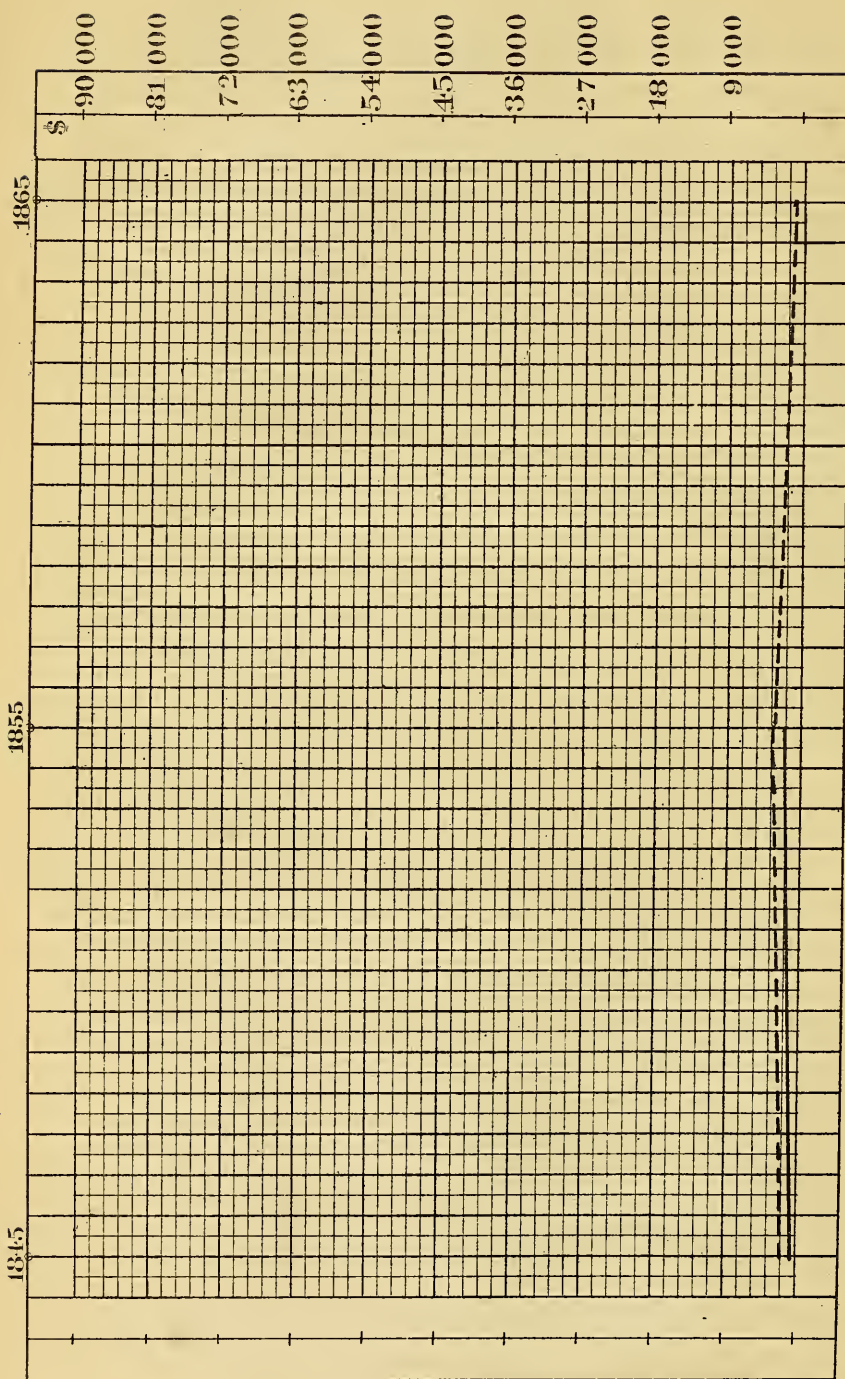
Ratio per square mile of total value of manufactured products of each area.
 (Omitting Framingham & Billerica.)
 Mystic..... Charles..... Sudbury--- Shawshine---



Ratio per square mile of value of manufactured products of Class I.

Mystic..... Charles---- Sudbury— Shawshine----

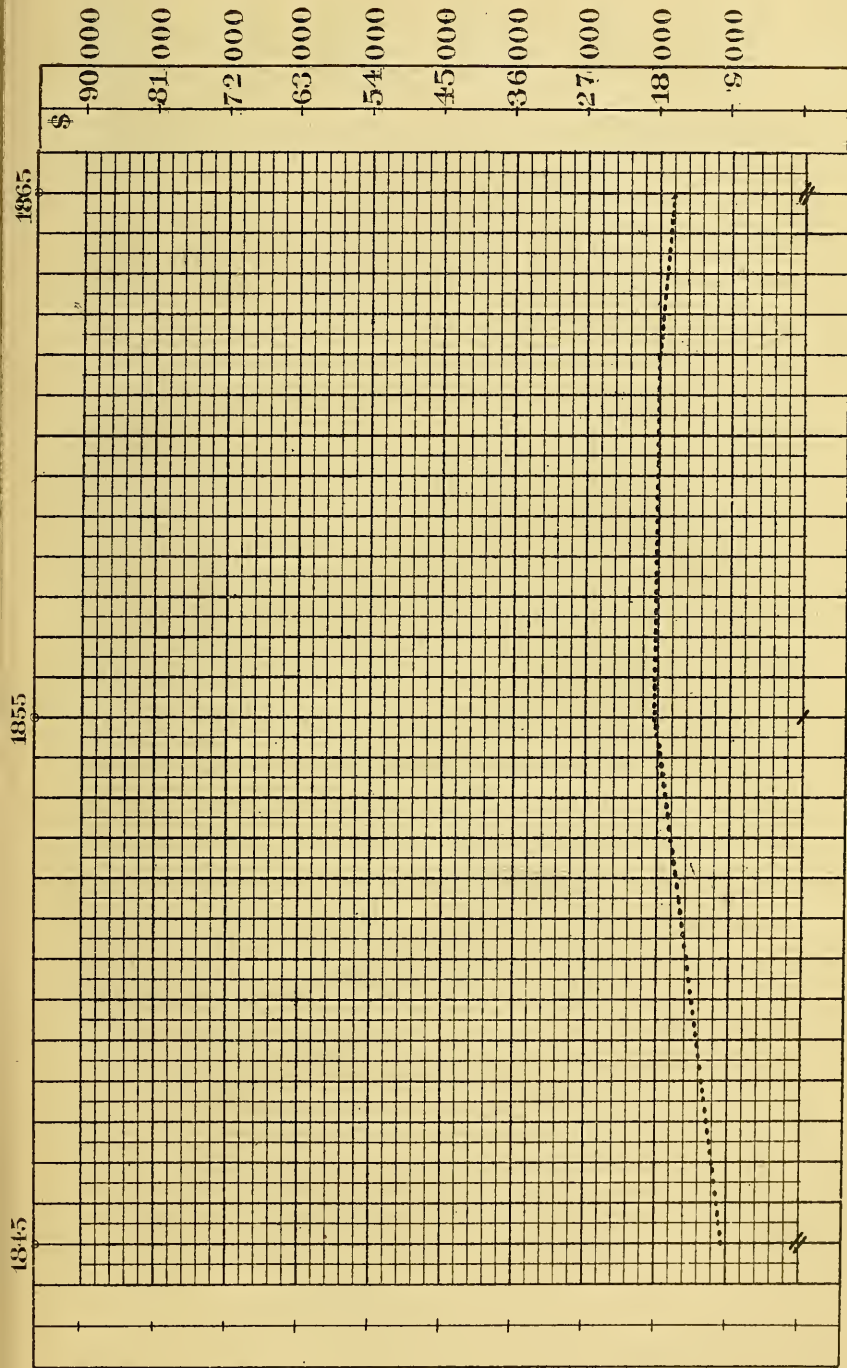
VI.



Ratio per square mile of value of manufactured products of Class II.

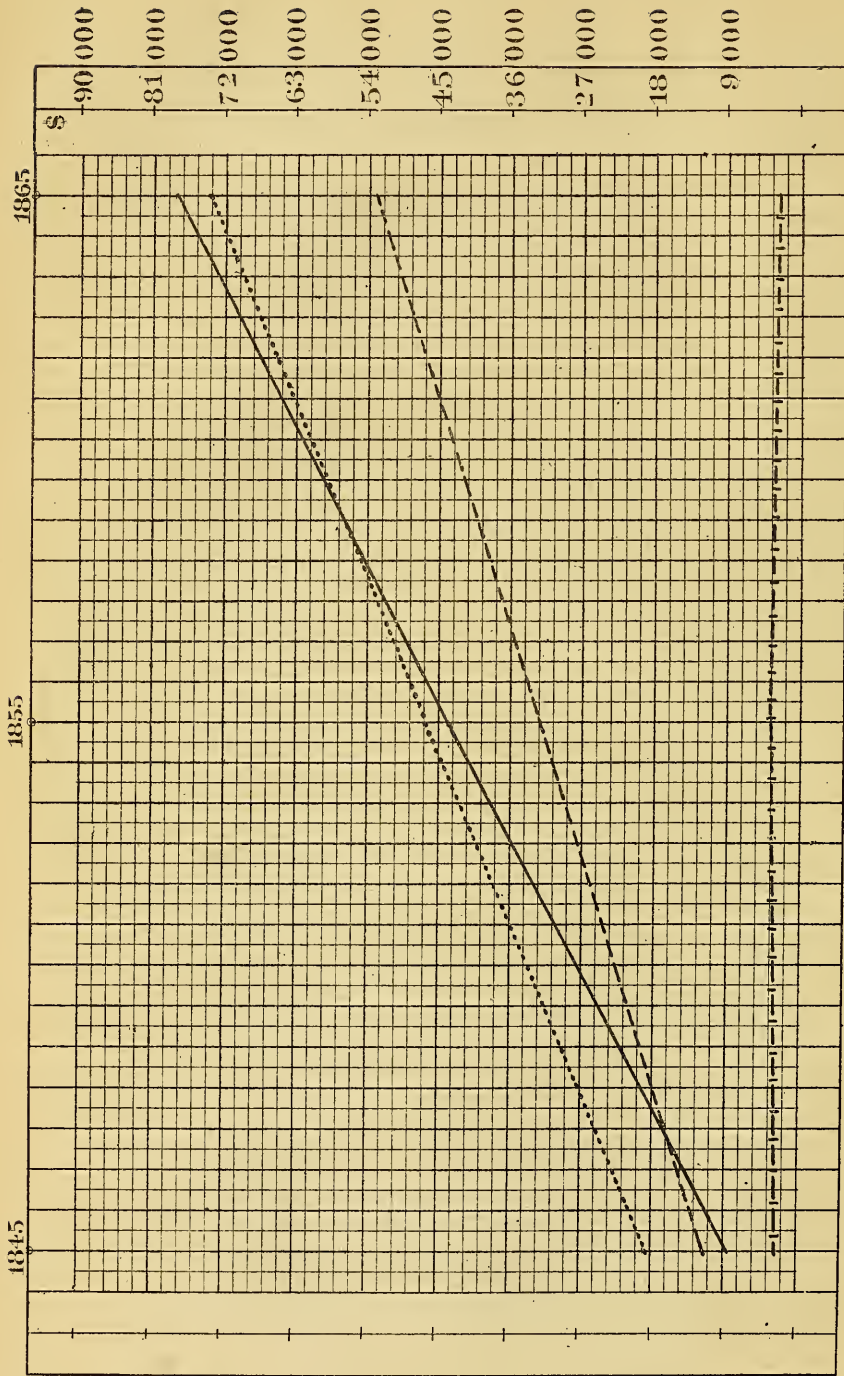
. Charles. --- Sudbury ---

VII.

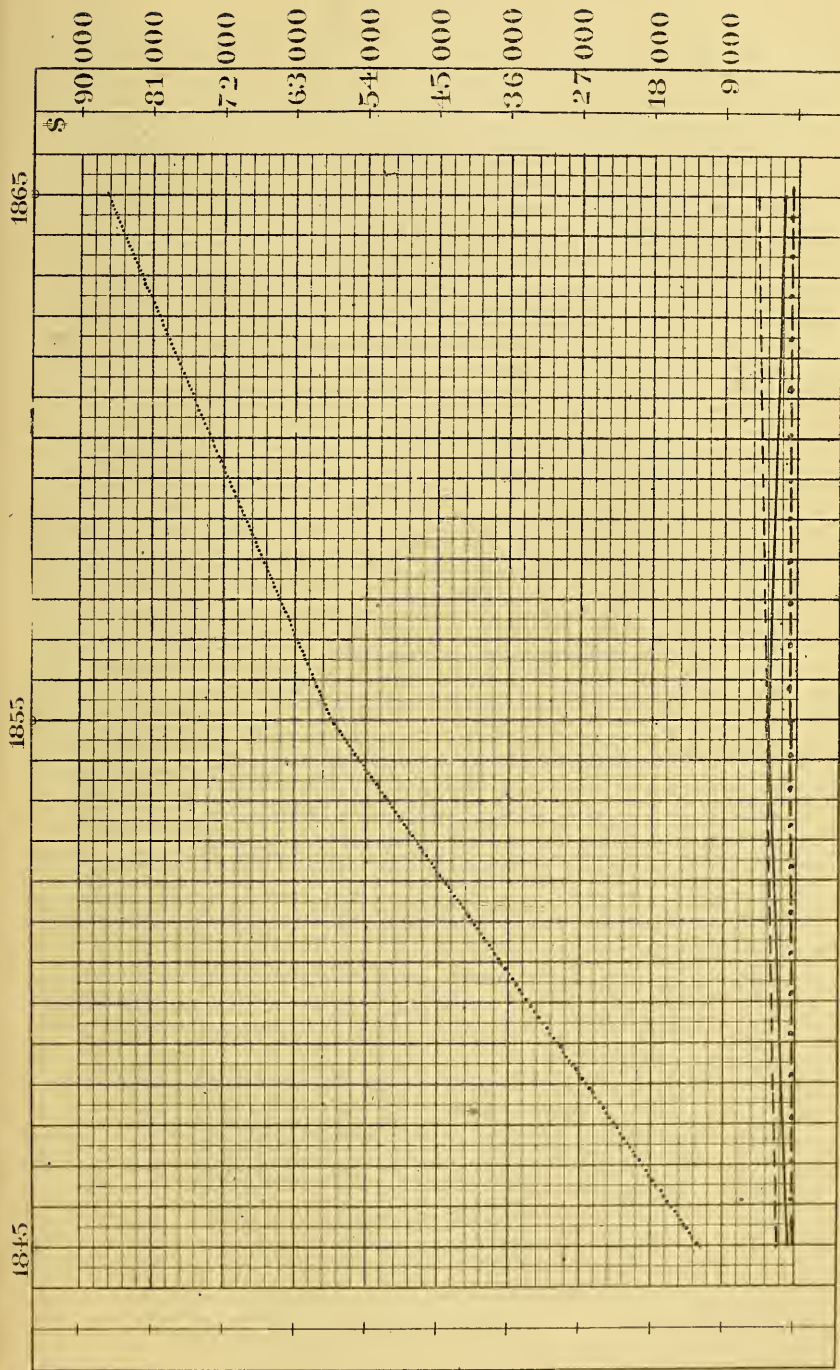


Ratio per square mile of value of manufactured products of Class III.

Mystic,..... Charles,..... Sudbury,--- Shawshine,---



Ratio per square mile of value of manufactured products of Class IV.
Mystic..... Charles ---- Sudbury — Shawshine -.-.-

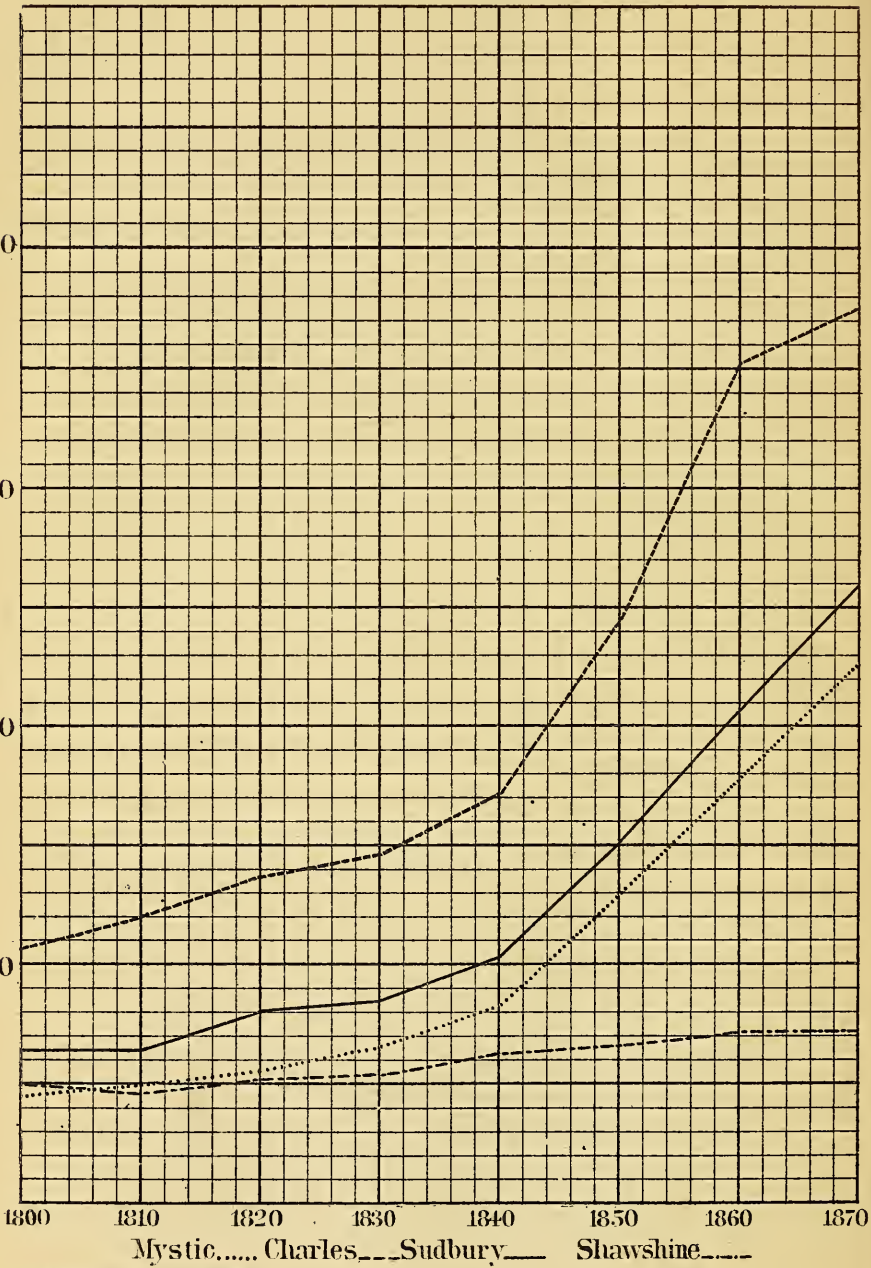


Ratio per square mile of value of manufactured products of Classes I. II. III.

Mystic,..... Charles,--- Sudbury,—— Shawshine,---

X.

Curves representing the absolute increase of population intowns lying wholly or in part in the four drainage areas



XI.

Curves representing the percentage growth of towns lying wholly or in part in the different drainage areas.

